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Agroforestry parklands in sub-Saharan Africa

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by
J.-M. Boffa

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Foreword

The ecological and socio-economic importance of traditional agroforestry systems is now widely recognized. These land-use systems provide various useful products for household and national economies including food and medicinal products for humans and animals, wood for construction and fuel, and cash income. They contribute to the sustainability of soil nutrient and water cycles and buffer climatic extremes. This is particularly true of agroforestry parklands, the most widespread agroforestry systems in the semi-arid zones of West Africa. Their social and ecological values also carry a high significance. This and the fact that they have been subject to severe droughts and utilization pressure in the last decades have led to a growing interest in promoting their conservation and in further improving their management to increase the benefits they provide to farmers.

A basic challenge in the field of agroforestry is how to make a tangible difference for farmers. The capacity of researchers, practitioners, conservationists and policy-makers to learn how to assist farmers to manage agroforestry parkland systems in more productive and sustainable ways relies primarily on the availability of cogent, comprehensive, up-to-date information, which reflects the complex nature of farmers' decisions. The initiative taken by FAO to contribute to a better knowledge of concepts and the synthesis of experiences relating to Soudano-Sahelian parklands reflects the awareness of the Organization of the roles and functions of these systems.

Several meetings and publications have helped research and development efforts in this field. A particularly significant event was the 1993 conference on Agroforestry Parklands of the West African Semi-Arid Lands organized by ICRAF in Ouagadougou, which brought together people from various disciplines and geographic areas. Other major initiatives include the recent ICRAF/SALWA country reports on parklands in Senegal, Mali, Burkina Faso and Niger, the 1991 ICRISAT-ICRAF workshop on *Faidherbia albida* in the West African semi-arid tropics in Niamey, CIRAD-Forêt's works on *F. albida* including the 1998 monograph on the species, and the 1998 Working Meeting on shea nut tree (*Vitellaria paradoxa, karité)* at FAO. The recent *Vitellaria paradoxa* and *Parkia biglobosa* monographs from the University of Wales at Bangor add to this interesting collection. In order to give a renewed impetus to the work on these systems, FAO felt that the time was ripe to attempt the production of a state of knowledge paper integrating a wide range of information on the biophysical, socio-economic and policy aspects relating to the understanding and sustainable management of parkland spe-

cies and systems. Jean-Marc Boffa, who has done extensive systems-oriented research, both biophysical and socio-economic on *Vitellaria* parklands in West Africa was an excellent candidate to be assigned the task.

The project originated with and has been coordinated by El-Hadji Sène, Chief of Forest Conservation, Research and Education Service in the Forest Resources Division of FAO's Forest Department. Susan Braatz, then forestry officer in charge of agroforestry in the Forest Resource Division started off the process. Michelle Gauthier, replacing Susan Braatz, took up the final steps of the project. Lise Andreasen and Michel Malagnoux have provided valuable comments and been involved in its follow-up. FAO also commissioned six parkland experts, Edouard Bonkoungou, Denis Depommier, Mark Freudenberger, Amadou Maïga, Madické Niang, and Kathrin Schreckenberg, to carry out a thorough review of the document. Technical and copy-editing was undertaken by Kathrin Schreckenberg from the Overseas Development Institute in London.

This study is part of the Conservation Guides series. It is targeted at all those with an interest in rural development, particularly agroforestry practitioners and researchers, but also policy- and decision-makers in the fields of agriculture, forestry and conservation in West Africa and beyond. I hope that it will encourage more integration in approaches, a higher degree of multidisciplinarity and more practical solutions to rural needs. It will be particularly useful for people working in the Sahel and Sudan zones of West Africa, but should also be of interest to a wide range of professionals working on agroforestry systems in other regions of the world outlining, as it does, many concepts underlying the value of trees within farming landscapes. This review is also relevant to FAO's interest and involvement in the assessment of forest resources outside forests, which are of increasing importance as pressure on resources in natural forest and tree stands rises. More research cooperation in development and dialogue on parklands are still needed and FAO welcomes observations and comments from readers for inclusion in future related studies.

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Director
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Abstract

This document attempts to present the current state of knowledge on agroforestry parkland systems. These systems, which for many local populations are very important for food security, income generation and environmental protection, are found primarily in the semi-arid and sub-humid zones of West Africa. The document first provides a thorough description of their distribution and diversity and discusses different ways of classifying them. It also presents data on current trends in parkland development and assesses determining factors. The document then provides an in-depth analysis of biophysical tree-soil-crop interactions and the factors regulating them, and describes various improved parkland management techniques. It goes on to examine the strength and limitations of institutional arrangements as well as the constraints imposed by Sahelian forest policies on the sustainable management of parklands. The production, use and marketing of parkland products is reviewed with an emphasis on their contribution to food security, local and national income as well as social values. Overall costs and benefits of the practice of parkland agroforestry are evaluated. In conclusion, the document identifies crucial research needs and promising avenues for promoting sustainable management of parkland systems.

Illustrations

Permission to use *Vitellaria paradoxa*, *Parkia biglobosa* and *Balanites aegyptiaca* distribution maps was kindly provided by Bangor University and specific thanks go to Jeremy Williams for supplying the first two in the correct format. Thanks are also expressed to CIRAD-Forêt for permission to reproduce the map of *Faidherbia albida* in Western Senegal. Photographs were provided by Christelle Bernard, Jean-Marc Boffa, Pascal Danthu, Roberto Faidutti, Dominique Louppe, Peter Lovett, Eliot Masters, Sibidi Jean Ouédraogo, Régis Peltier and Kathrin Schreckenberg.

List of Acronyms

AFRENA	Agroforestry Research Network for Africa
APROMA	Association des produits à marché (Bruxelles, Belgique)
ARD	Associates in Rural Development (Vermont, USA)
CADEF	Comité d'action pour le développement de Fogny (Sénégal)
CBE	Cocoa butter equivalent
CBRs	Cocoa butter replacers
CDR	Comité pour la défense de la révolution (Burkina Faso)
CEC	Cation exchange capacity
CFDT	Compagnie française de développement des textiles (France)
CIEPAC	Centre international d'éducation permanente et d'aménagement concerté (Senegal)
CIFOR	Centre for International Forestry Research (Indonesia)
CILSS	Permanent Interstate Committee for Drought Control in the Sahel / Comité inter-états de lutte contre la sécheresse au Sahel
CINTEC	Compagnie internationale de négoce en transport et commerce (Burkina Faso)
CIRAD-SAR	Centre de coopération internationale en recherche agronomique pour le développement, Département systèmes agroalimentaires et ruraux (France)
CITEC	Compagnie industrielle du textile et du coton (Burkina Faso)
CNSF	Centre national de semences forestières (Burkina Faso)
COVOL	Cooperative Office for Voluntary Organizations of Uganda (Uganda)
CTFT	Centre technique forestier tropical (today CIRAD-Forêt) (France)
dbh	Diameter at breast height
DFSC	DANIDA Forest Seed Center (Humlebaek, Denmark)
ENEA	École nationale d'économie appliquée (Senegal)
FCFA	CFA franc (Communauté financière africaine) — currency used in French-speaking West Africa
GERES-CTFT	Groupe d'études sur la restauration des sols, Centre technique forestier tropical (France)
GIS	Geographic Information System
GRAAP	Groupe de recherche et d'appui pour l'auto-promotion paysanne
IAA	Indol-3-acetic acid
IBA	Indol-3-butyric acid
ICRAF	International Centre for Research in Agroforestry (Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (Niger)
ILCA	International Livestock Centre for Africa (Ethiopia) (today, International Livestock Research Institute, Nairobi, Kenya)
IDRC	International Development Research Center (Canada)
IPGRI	International Plant Genetic Resources Institute (Italy)
IRHO	Oils and Oilseeds Research Institute / Institut de recherche pour les huiles et oléagineux

ISRA	Institut sénégalais de recherche agricole (Sénégal) / Agricultural Research Institute of Senegal
IUFRO	International Union of Forestry Research Organizations (Austria)
KES	Kenyan Shilling
LTC	Land Tenure Center, University of Wisconsin-Madison (USA)
NAA	Napthalene acetic acid
NARS	National agricultural research systems
NGO	Non governmental organization
NTFPs	Non-timber forest products
ODEPA	Oficina de Planificación Agrícola (Chile)
ORSTOM	Office de la recherche scientifique et technique outre-mer (today, Institut de Recherche pour le Développement, IRD) (France)
PAR	Photosynthetically active radiation
PRSPR	Programme de recherche sur les systèmes de production ruraux (Mali)
R&D	Research and development
RDBF	République du Burkina Faso
RDM	République du Mali
RDN	République du Niger
RDS	République du Sénégal
SALWA	Semi-Arid Lowlands of West Africa
SOCADA	Société centrafricaine de développement agricole Central African Agricultural Development Agency
SODECOTON	Société de développement du coton (Cameroon)
UNIFEM	United Nations Development Fund for Women
USAID	United States Agency for International Development

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Introduction

In the semi-arid and sub-humid zones of West Africa, farmers have for many generations maintained a traditional land-use system, known as the 'agroforestry parklands' system (Pullan, 1974; Raison, 1988), which is characterized by the deliberate retention of trees on cultivated or recently fallowed land. Trees are an integral part of the system, providing food, fuel, fodder, medicinal products, building materials and saleable commodities, as well as contributing to the maintenance of soil fertility, water conservation and environmental protection.

Demographic, economic, environmental and social developments in the past 30 to 40 years have put pressure on traditional land-use systems and led to various forms of degradation. The severe droughts of the 1970s drew attention to the loss of tree cover and led the research and development community to devote a great deal of effort to trying to involve farmers in various types of tree-planting schemes. However, local participation was often short-lived and management not successful because little consideration was given to the reasons why farmers may protect or grow trees. Gradually, there was a growing awareness that trees needed to be regarded as an integral component of an overall farming system and a complex decision-making environment with interdisciplinary interactions. Dealing with many age-old practices, the new science of agroforestry was seen to provide promising solutions to the problem of degraded land-use systems and became the focus of strong research and development interest.

As part of this trend, the agroforestry parklands of the Sahel and Sudan zones of West Africa have aroused particular interest in recent years. At a time when human pressures on resources are high in natural forest ecosystems, and when more tree-related needs are being or will need to be met on-farm (Holmgren *et al.*, 1994; Falconer, 1990; FAO, 1995), parkland agroforestry has a vital and increasingly important role to play.

Since the first descriptions of these systems in the late 1800s, followed by the seminal characterization work of geographers (Sautter, 1968, cited in Raison, 1988; Pélissier, 1964, 1966) and early agronomic research in the 1960s, the knowledge base on agroforestry parklands has been greatly advanced in the last 20 years. It has branched out to encompass research on tree-soil-crop biophysical interactions, system characterization, tree production, indigenous knowledge, genetic diversity, domestication, processing technologies, marketing systems, nutrition, social aspects, traditional tenure arrangements and policy analysis, all of which have contributed to a deeper understanding of the key characteristics, constraints and opportunities in these systems.

However, research results have been insufficiently disseminated as the abundant and diverse literature on these systems remains scattered and fragmented, so that knowledge gaps and new research priorities are not always easily identified. As in other areas of agroforestry research, the greatest challenge for work on parklands is perhaps the need to achieve a truly multidisciplinary approach, bringing together different areas of expertise, to provide integrated and practical solutions to farmers' problems. To be successful, this needs to involve the large variety of actors who participate in the promotion and management of agroforestry systems (Mallet and Depommier, 1997).

This review attempts to synthesize the state of knowledge on the wide diversity of inter-related factors, whether biophysical, nutritional, socio-cultural, economic or political, which underlie the practice of parkland agroforestry and govern its management and evolution. It also outlines the main avenues for sustaining and

improving these systems as well as the kinds of data and experiences which would help to address unanswered questions. In doing so, it hopes to raise awareness of the local importance of parklands and the significant contribution they can make to sustainable natural resource management and enhanced livelihoods, and to promote greater commitment and coordination of efforts to maintain and improve these systems.

The study deals with agroforestry parkland systems in Sub-Saharan Africa. However, the main emphasis is on the semi-arid and sub-humid zones of West Africa, with occasional references to central, eastern and southern Africa. Agroforestry systems with scattered multipurpose trees in fields and fallows are its main target and other agroforestry configurations and technologies such as live fences, fodder banks, etc., which are also found within parkland systems, were not investigated.

The report emphasizes the central role which farmers play in establishing and maintaining parklands and suggests that, despite conditions which have led to degradation in many places in the Sahel, these systems are remarkably dynamic and resilient. They are not in uniform decline but, in several locations, are reproducing themselves very effectively through the concerted efforts of rural populations. The expectation that tree cover diminishes as pressure on land increases does not always hold true and land-use intensification in some places is accompanied by growing densities of managed trees (Arnold and Dewees, 1995). A variety of improvements in the institutional, economic, technological and biological environment in which these systems operate can effectively lead to the emergence and extension of agroforestry parklands.

The first chapter of the report provides a thorough description of agroforestry parkland systems. It reviews the various concepts and definitions of the system, emphasizes the wide geographical extent of their distribution and provides details on constituent species. Various classification systems, which have attempted to capture regional and local variations in parkland structure and composition, are presented.

Chapter two assesses dynamic trends in the extent, density and age distribution of parklands over time and highlights the need for more information in this area. It also outlines the variety of natural, socio-economic, technological, political and demographic variables to which farmers and parkland systems respond, and which have influenced adoption and decline of this agroforestry practice in the last few decades.

The third chapter analyses in detail the available qualitative and quantitative information on biological processes governing the biophysical influence of parkland trees on soils, crops and microclimate, and how they interact to have a positive or negative impact on crop yields. These processes are examined in relation to several factors including tree species, distance from tree, tree and crown size, and tree density.Experience with various improved parkland management techniques is presented in Chapter four. These technologies aim to improve parkland tree density, increase fruit, foliage and wood production, as well as enhancing crop production. Advances in domestication of parkland species and its potential impact on the adoption of parkland agroforestry are considered. This is followed by a discussion of knowledge gaps relating to the processes regulating genetic diversity in parkland species, with a view to promoting their conservation.

Chapter five focuses on the institutional factors influencing the management of land and trees in parklands. It highlights the need to understand existing indigenous arrangements at the level of whole communities or individual farmers for managing and regulating the use of parkland resources and the ways in which they have

evolved in response to changes in the socio-economic and environmental context. Constraints and incentives for tree conservation and planting in indigenous tenure are analysed. The second part of the chapter looks at how the implementation of Sahelian forest laws has limited farmers' rights and prevented them from optimizing parkland management. It suggests possible areas of improvement in national forest policies and institutions which might help local communities achieve sustainable forest management.

Within the context of the increasing importance of on-farm tree production, Chapter six presents available data on fruit, foliage, wood and gum production in parklands and outlines additional data needs.

Chapter seven reviews the quantitative and qualitative use of parkland outputs and their importance in human nutrition, food diversity and seasonality, and health. It also emphasizes the diversity and size of local and international markets for parkland products and the role they play in local and national incomes. Their particular significance for specific gender, ethnic and social groups, who participate in the various stages of product collection, processing, marketing and consumption, is analysed. Lastly, the costs and benefits associated with the practice of maintaining trees in agroforestry parklands are evaluated.

The final chapter offers salient conclusions regarding the importance and characterization of agroforestry parkland systems, and the driving forces behind them, recommending several major lines of action for sustaining their conservation and reproduction.

AGROFORESTRY PARKLAND SYSTEMS

CHAPTER 1

Parklands: A review of definitions and terminology

Parklands are generally understood as landscapes in which mature trees occur scattered in cultivated or recently fallowed fields (Pullan, 1974; Sautter, 1968, cited in Raison, 1988). In the ICRAF Agroforestry Systems Inventory, agroforestry parklands are included in the very general category of 'multipurpose trees on farmlands' (Nair, 1985). Livestock production may be a significant or secondary component in these systems. Because of the variety of field realities encompassed, the notion of parklands has been interpreted widely and its terminology is still very much under discussion.

On the one hand, parklands have been referred to as a vegetation type. They are physiognomically comparable to 'tree savannas' and have been referred to as such. The terms 'savanna parkland' and 'park savanna' or 'parklike savanna' are sometimes used by phytogeographers. Specifically, Cole (1986) defined savanna parklands as "tall mesophytic grassland (grasses 40-80 cm high) with scattered deciduous trees (less than 8 m high)" in a savanna classification first proposed in 1963. This vegetation type is intermediate between savanna woodlands, "deciduous and semi-deciduous woodland of tall trees (more than 8 m high) and tall mesophytic grasses (more than 80 cm high)", and savanna grasslands, defined as "tall tropical grassland without trees or shrubs". In Cole's analysis, savanna parklands occur in Australia and in Africa, mostly in Central and Southern Africa, but not in South America, with the exception of the region of the High Pantanal. Forests with a very open canopy and a history of frequent fire in Western Canada and northwestern United States are also called parklands (British Columbia Ministry of Forests, 1991).

The term 'parkland' as used in this report specifically applies to landscapes derived from human agricultural activities.

However, while tree savannas can occur naturally or as a result of edaphic features, fire and grazing in the absence of cultivation, the term 'parkland' as used in this report specifically applies to landscapes derived from human agricultural activities (Pullan, 1974). In parklands the composition and density of the woody vegetation is altered in order to facilitate its use. Most often parklands are not the product of a single agricultural season, but reflect a slow process of species selection, density management, and tree growth over one or several decades. Parklands, in the strict sense of the word, are specific to permanently cultivated fields or fields where fallow duration is shorter than necessary for the regeneration of a second-growth forest (Seignobos, 1982; Raison, 1988). They would not, therefore, include the relic of a natural forest temporarily left standing by frontier farmers (Pélissier, 1980a).

Parkland trees stand out as an important component of the spatial structure of the landscape (Sautter, 1968, cited in Raison, 1988; Seignobos, 1982). Parkland attributes include a regular distribution of relatively even-aged trees or shrubs and a low tree density so that tree cover is never continuous. Their name derives from their resemblance to urban or rural recreational parks with large scattered trees in expanses of grass. Examples of parklands are more common in the semi-arid or subhumid tropics, and particularly in West Africa which will be the main subject of this report as it is of most of the literature reviewed in it.

Parklands are not, however, limited to the Sahel and Sudan zones of Africa. While they may not generally be called parklands, systems with scattered trees in fields with similar appearance and purpose are also widespread in Zimbabwe (Campbell *et al.*, 1991) and Malawi (Maghembe and Seyani, 1991) and elsewhere in southern Africa. Several systems in Asia, Oceania, and Latin America would qualify as agroforestry parklands by definition. Information on practices in these areas is more limited, however (Baumer, 1994; Raison, 1988). In India, the well-known *Prosopis cineraria* is commonly protected in fields planted with millet and legumes, and occurs on fallows and grazing lands in the semi-arid zone of Rajasthan (Mann and Saxena, 1980). Farmers value its high ecological combining ability and suitability for pruning and fodder as well as its socio-cultural significance. Other species found in these systems include *Ziziphus nummularia*, *Acacia nilotica* var. *cupressiformis* and var. *radiane*, *Acacia leucophloea*, and *Salvadora persica* (Shankarnarayan *et al.*, 1987). In the state of Tamil Nadu, several tens of multipurpose tree species are naturally regenerated or planted on farmlands (Jambulingam and Fernandes, 1986). To cite only a few, *Borassus flabellifer* is grown with cereals and pulses, *A. leucophloea* with millet and horsegram, and *A. nilotica* in rice fields.

Parkland or related systems also exist in temperate regions. *Dehesa* (Spanish) or *montado* (Portuguese) systems are centuries old, mainly silvipastoral systems in southwestern Spain and southeastern Portugal where holm oak (*Quercus rotundifolia*, syn. *Quercus ilex*) and cork oak (*Quercus suber*) are scattered in pastures or cereal (oats, barley, wheat) fields (Joffre *et al.*, 1988; Janick *et al.*, 1987). Trees are sometimes seeded and systematically pruned for better fruit and wood production. They provide highly nutritious acorns for fodder and timber, charcoal, tannin, cork (*Q. suber*), etc. With a density of 20 to 40 trees per hectare, the tree cover may be 5 to 20 percent. This system extends over an estimated 5 million ha in Spain and more than 500 000 ha in Portugal. Similar systems with the same or different species (olive, carob, etc.) also exist in other Mediterranean countries including Morocco, Algeria, Tunisia, southern France (mainly Corsica), Italy (Sardinia) and Greece (Joffre *et al.*, 1988). Moreover, the *Acacia caven* silvipastoral system is widespread in the semi-arid and subhumid Mediterranean climate zone of Chile, covering 1.5 million ha (ODEPA, 1968, cited in Ovalle and Avendano, 1987). Walnut plantations in the Touraine and Berry regions of France may be included in the parkland family (Raison, 1988). The oak savannas of the eastern United States (New York State) may also be a case of parklands with a silvipastoral focus.

The term 'agroforestry parkland' emphasizes the multiple forms and purposes of agroforestry systems.

Among '*parcs arborés*', the usual French term for parklands, Baumer (1994) distinguished between systems primarily used for cultivation and those used for pastoralism. He suggested '*forêt-parcs*' as the term for parklands resulting from a high degree of human influence, where trees tend to be monospecific, even-aged, regularly spaced, and form a cover ranging from 1 to 25 percent, and where annual crops, generally cereals, are cultivated, sometimes manured, and grazed after harvest. These trees usually have a positive ecological role (soil fertility or wind reduction) and a strong economic significance. In contrast, '*parcs arborés*' would describe systems with a parkland appearance but which have not been heavily manipulated by human beings, and are primarily used for pastoralism and gathering of tree products. Examples of such vegetation types include cattle-raising areas in Brazil, such as the open forests of the Sao Paulo and central-east regions, highly forested grasslands of southeastern Queensland in Australia, *Miscanthus* grasslands under forest relics in Indonesia, and the *Daniellia oliveri* open dry forests of East Africa. Although the term '*parcs arborés*' only draws attention to the tree component of the landscape, the term '*forêt-parcs*' is more problematic. '*Forêt*' suggests a low degree of human intervention and conceals the major distinction between this and other systems, namely that canopies are spatially scattered rather than forming a closed cover (Depommier, 1996a).

The major English writings on this topic have used the word 'parkland' (Pullan, 1974; Bonkoungou *et al.*, 1994, 1996). Sometimes, however, it is used to describe lands in parks, which bear no relation to the agroforestry parklands considered in this report. The term 'park' is sometimes found as a direct English translation of the French '*parc*', but this is even less explicit than 'parkland' and is easily confused with the more common meaning of park as an enclosed or delimited land area managed for preservation or recreation. The term 'farmed parkland' is used by Pullan (1974) to encompass parklands being farmed as well as land lying fallow, and does not exclude a pastoralist component. Other labels such as 'farm parkland', and 'cultivation parkland' have also been used but are less common. The term 'agroforestry parklands' incorporates these systems in the fast-growing discipline of agroforestry. It was chosen for this study because it emphasizes the multiple forms and purposes of these systems, and thus includes various schools of thought. As defined by Bonkoungou *et al.* (1994), agroforestry parklands "are land-use systems in which woody perennials are deliberately preserved in association with crops and/or animals in a spatially dispersed arrangement and where there is both ecological and economic

Table 1.1 Scientific, English and French names of common parkland trees

Scientific name	English name	French name
Acacia senegal	Gum arabic	Gommier
Adansonia digitata	Baobab	Baobab
Anogeissus leiocarpus		Bouleau d'Afrique
Balanites aegyptiaca	Desert date	Dattier du désert
Bombax costatum	Red flowered silk cotton	Kapokier rouge
Borassus aethiopum	Fan palm	Rônier
Ceiba pentandra	Silk cotton	Fromager
Diospyros mespiliformis	Ebony	Faux ébenier
Elaeis guineensis	Oil palm	Palmier à huile
Faidherbia albida (syn. Acacia albida)	Winterthorn	Kad, Faidherbia
Hyphaene thebaica	Dum palm	Palmier doum
Lannea microcarpa		Raisinier
Parkia biglobosa	African locust bean	Néré
Sclerocarya birrea	Marula	Prunier
Tamarindus indica	Tamarind	Tamarinier
Vitellaria paradoxa (syn. *Butyrospermum paradoxum*)	Shea nut tree	Karité, arbre à beurre
Vitex doniana	Black plum	Prunier noir
Ziziphus mauritiana	Jujube	Jujubier

interaction between the trees and other components of the system". This emphasis on interactions is positive and helpful for a finer understanding of the systems by the research and development (R&D) community, but may be extraneous from a farmer's holistic point of view.

As mentioned in the introduction, agroforestry is an ancient practice but a relatively new science. In order to assess the significance of the parkland system, it is important to characterize it physically, determine its zone of occurrence, and identify and describe existing parkland types. The next section sets the geographical stage, beginning with a review of the main historical studies of parklands. This is followed by a presentation of the main modes of investigation and existing data, on the basis of which a tentative picture of the wide spatial extension of agroforestry parklands and the distribution and density of prominent parkland species (see Table 1.1) is drawn.

Parklands in West Africa

Being linked to human activities, parklands occur in various latitudes and are not confined to specific agroecological zones. Nonetheless, the most well-known and described parklands are located in semi-arid or subhumid zones where tropical savannas, broadly defined as tropical grasslands with scattered trees (Bourlière and Hadley, 1983), occur.

We are indebted to the early explorers for the first references to African parklands (Pullan, 1974). Mungo Park described the frequent occurrence of *Vitellaria* parklands along the Niger River from Segou towards the east in Bambaraland (Miller, 1954), while Caillié (1830) noted the various tree species around houses and *Vitellaria* and *Parkia* trees in the surrounding agricultural landscape. On his travels to Hausaland in Nigeria, Clapperton (1829) described well-maintained *Vitellaria*,

Parkia and *Tamarindus* trees located in agricultural lands. The early reports also focused on how products from these species were prepared for various human and animal uses. In the late 1800s, scientific and commercial interest in savanna and parkland species grew. Plant collections were undertaken and tropical African floras prepared, while tree products were sampled and investigated for commercial use in colonial countries of the North.

Their origin in people's agricultural activities has given parklands a peculiar scientific status amongst plant communities. Pullan (1974) noted that plant ecologists have generally neglected the study of vegetation in cultivated zones. Thus the degree to which parklands were recognized as distinctive vegetation types, or had their importance in successional stages of vegetation regrowth acknowledged, was variable among early plant scientists. Recognizing the widespread occurrence of *Faidherbia albida*[1] in the vegetation of southwestern Senegal, Trochain (1940) characterized it as a climax association (or, more specifically, a stable plant community of anthropogenic origin, which replaces the climax vegetation, including various forms of open forest found in the Sudan zone, on silica and clay-rich soils), developed after the species was introduced by nomadic people and their livestock. Roberty (1956) established distribution maps of parkland types in western Senegal (Fig.1.1), distinguishing major species in part based on a classification he established in the Middle Niger Valley. Pélissier (1953, 1966), Savonnet (1959), and Gallais (1967) also described *F. albida* parklands in Senegal, southern Burkina Faso and the inland delta of the Niger River, respectively.

Lely (1925) recognized a parkland type dominated by *Parkia*, *Vitellaria*, *Afzelia*, *Tamarindus* and *Acacia* species in Nigeria. Vegetation maps for northern Nigeria (Clayton, 1962, 1963) took into account Keay's (1959) contribution to the recognition of local parkland types. The Samaru Soil Survey Bulletins (1956-71)

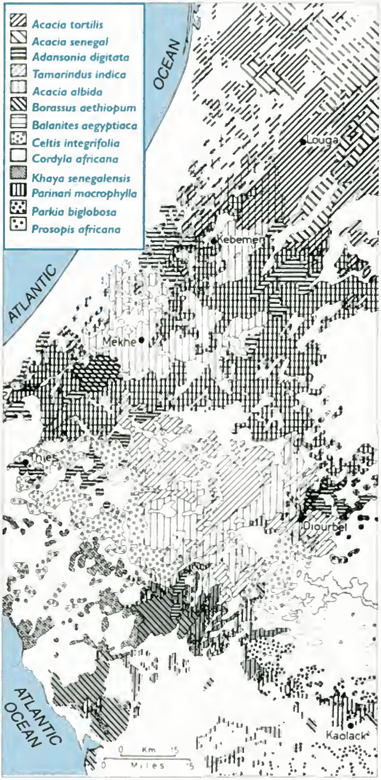


Fig. 1.1 Distribution and types of farmed parkland in western Senegal (Source: after Roberty, 1956, shown in Pullan, 1974).

[1] The scientific name of *Faidherbia albida* has been discussed for many years. The species was first named *Acacia albida* by Delille in 1813. Baillon observed in 1863 that its staminal characteristics departed from the pattern usually found in the Acaciae tribe. This distinction which relates it more closely to the Ingeae tribe, as well as variations in phenology, leaf, cotyledon, pollen and wood anatomy reviewed in CTFT (1988), led Chevalier in 1934 to propose a new monospecific genus *Faidherbia* located between the Acaciae and the Ingeae tribes. This name has been adopted by many authors since, but not unanimously. In order to emphasize its divergence from members of the *Acacia* genus, the use of *Faidherbia albida* has been recommended until its taxonomic position is clearly established (CTFT, 1988). *Faidherbia albida* is therefore used in this report.

also mention parklands in northern Nigeria including *Parkia, Vitellaria, Ficus, Balanites, Adansonia, Hyphaene* and *Borassus species* and *F. albida*. Three types of parklands, dominated by *F. albida, Vitellaria-Parkia*, and *Parkia* species, are described by FAO (1969) in northwestern Nigeria. In the northeastern part of the country, Leeuw and Tuley (1972) mapped *F. albida, Adansonia* and *Parkia* parklands, while *Ceiba* parklands were reported by Jackson (1970) around Zaria.

In northern Ghana, Taylor (1960) identified *Vitellaria-Parkia-Tamarindus* and *Adansonia-Tamarindus* parkland associations, with small parkland patches of *F. albida*. Irvine (1961) also referred to mature *F. albida, Parkia* and *Borassus* parklands, and *Vitellaria-Parkia* communities were described by Ramsay and Innes (1963). Wills (1962) also referred to farmed parklands in this area. Early citations for Niger include Dundas (1938) and Fairburn (1945), yet the relationship of the described vegetation to parklands was not clearly made (Pullan, 1974). Parkland communities dominated by *Vitellaria, Parkia, F. albida, Borassus* and *Hyphaene* were reported by Pias (1955) in the Chari-Logone lowlands of Chad and Cameroon.

Parklands did not become a major object of study until fairly recently, perhaps because their definition did not fit squarely into any single discipline. Thus, as noted by Pullan (1974), they fell outside of uncultivated plant communities, the 'classical' field of study of plant ecologists. Similarly, in the early days there were only isolated scientific investigations of parklands by agronomists or foresters, the latter having focused on natural forests and industrial or village plantations. The first in-depth system descriptions were in fact undertaken by geographers (Sautter, 1968, cited in Raison, 1988; Pélissier, 1964, 1966). It was only the emergence of agroforestry as a scientific discipline in the 1980s that finally established the study of parklands in their own right.

The Semi-Arid Lowlands of West Africa (SALWA) Programme of the International Centre for Research in Agroforestry (ICRAF) has contributed to gathering and generating information on parklands in its member states: Burkina Faso, Mali, Niger and Senegal. The Macro- and Micro-Diagnostic and Design exercises conducted in the first half of the 1990s advanced the identification, description and general analysis of the various agroforestry land-use systems on a national basis (see for instance ICRAF, 1990). National parkland reviews carried out within the African Research Network on Agroforestry (AFRENA) in SALWA countries (Sall, 1996; Cissé, 1995; S.J. Ouédraogo, 1995; Ounteni, 1998) represent an important step in synthesizing knowledge on these systems. Maps and parkland typologies have also been produced by ICRAF (1996) for the Dori area, Burkina Faso, and the middle Bani-Niger river basin and Gondo-Mondoro region of Mali.

Areal extent

Parklands constitute the predominant agroforestry system in semi-arid West Africa.

Parklands occupy a vast land area, representing a large part of the agricultural landscape under subsistence farming in the tropics and constituting the predominant agroforestry system in semi-arid West Africa (Nair, 1993; Bonkoungou *et al.*, 1994). In Mali, the agroforestry parkland system occupies about 90 percent of the agricultural land area (PIRL, 1988, cited by Cissé, 1995) and is practised by an estimated 2.5 million people on the Mandingue and Koutiala plateaux and the Moyen-Bani-Niger, High Dogon Plateau, Seno, Gondo, Bélédougou, Wenia, Falo and Central Delta zones (Djimdé, 1990). In Burkina Faso, parklands are found throughout settled zones where agriculture is practised, i.e. most of the country with the exception of the extreme North, East, and parts of the South and

Southwest where human population density is low (S.J. Ouédraogo, 1995). The parkland system is also recognized as the most common production system in Katsina State in northern Nigeria (Otegbeye and Olukosi, 1993). A discontinuous cover of scattered trees in crop fields is traditional in northern Ghana (Rudat *et al.*,1996). These references highlight the local or national significance of parklands but also serve to illustrate the lack of a coordinated quantitative assessment of this land-use system at the regional level.

Characterization by dominant species

Nowadays, agroforestry parklands are most often characterized by the dominance of one or a few species. Species composition is generally more diverse and variable, however, in areas located farther away from villages and only occasionally cultivated. In parklands, one or a few dominant species may prevail on a local scale or across large land areas with substantial variations in relative abundance, frequency and overall species composition. Thus, parklands are often described by their dominant species (Pullan, 1974; Weber and Hoskins, 1983). Table 1.2 provides a tentative list of the main species in each climatic zone. Seignobos (1982), however, notes that some parklands, such as those in the northern Mandara mountains in Cameroon or around Kimré in southern Chad, include a large diversity of species without apparent dominance. Otegbeye and Olukosi (1993) also report that parklands with a species mix without specific dominance are the most common types in Katsina State, northern Nigeria.

Whether or not there is a dominant species, parklands usually host a wide variety of tree and shrub species. For instance, 22 and 39 species were recorded in cultivated fields in two sites around Kano, northern Nigeria (Cline-Cole *et al.*, 1990), 43 and 46 in north-central and southern Burkina Faso (Gijsbers *et al.*, 1994; Boffa, 1995), and 46 in northern Côte d'Ivoire (Bernard *et al.*, 1996). Species diversity increases when fallows are included.

There is very little quantitative information regarding the relative representation of major species throughout the parkland range which could help to prioritize conservation and development efforts in a rigorous way. *Faiderbia albida* parklands have received considerable attention because of the generally observed positive effects of the tree on soil fertility and crop production. It is likely, however, that *V. paradoxa* and *P. biglobosa* parklands occupy the largest land area among parkland types. Breman and Kessler (1995) indicate that *V. paradoxa* may be the most common parkland species in semi-arid zones of West Africa. Prioritization exercises conducted by ICRAF (Franzel *et al.*, 1996) in selected sites have been

Table 1.2 Dominant species in West African parklands by climatic zone

Sahel	Northern Sudan	Southern Sudan	Northern Guinea
Acacia raddiana	*Faidherbia albida*	*Vitellaria paradoxa*	*Parkia biglobosa*
Balanites aegyptiaca	*Vitellaria paradoxa*	*Parkia biglobosa*	*Ficus sp.*
Hyphaene thebaica	*Parkia biglobosa*	*Faidherbia albida*	*Vitellaria paradoxa*
Acacia senegal	*Adansonia digitata*	*Borassus aethiopum*	*Daniellia oliveri*
Tamarindus indica	*Borassus aethiopum*	*Ficus gnaphalocarpa*	*Elaies guineensis*
Piliostigma reticulata	*Cordyla pinnata*	*Ceiba pentandra*	
Borassus aethiopum	*Tamarindus indica*	*Sterculia setigera*	
	Sclerocarya birrea		

(Source: adapted from Pullan, 1974)

useful in assessing the importance of parkland species in the eyes of farmers and thus guiding domestication programmes. There is a definite need for more quantitative data on the main parkland species at the regional level, including their distribution, stocking rates and dynamics, to improve the formulation of parkland research and development activities. Some methods for assessing parkland resources are reviewed in Box 1.1

The rest of this section reviews recent information on individual parkland species throughout their zone of occurrence. Species are reviewed in order of their importance in the literature. Where parkland studies included information on tree densities, these are listed in Tables 1.3, 1.4 and 1.5 for *F. albida, V. paradoxa*, and *P. biglobosa* respectively. Other species mentioned may seem less widespread but are equally important to farmers. Reports of particular species in agroforestry parklands are generally localized, but their wider distribution is by no means limited to these few geographical references.

Box 1.1

Methods for assessing parkland resources

A variety of natural resource assessment tools, such as remote sensing, geographical information systems and field inventories, are available to assess parkland resources. An exploratory study on the potential use of satellite imagery for quantifying the extension and density of *Faidherbia albida* parklands was tested in northern Cameroon (Triboulet, 1996). Satellite images taken in the dry season revealed vegetative activity. To eliminate activity associated with non-parkland vegetation (e.g. forests, roadside trees and off-season crop fields), a subjective but careful process of pixel selection was carried out, based on spectral values and the spatial arrangement of pixels, to reflect the likely presence of parklands.

The primary advantage of satellite imagery for parkland characterization is that the main parkland sites were precisely located, thus saving time and money, and an indication of their surface area was generated. However, as other evergreen tree species were also active when the image was produced, the relative abundance of tree species could not be assessed. While pixel density is proportional to actual tree density in the field, parklands with sparse, young or pruned trees could not be detected. The use of this technique may also be limited by the fact that, with the exception of *Faidherbia albida*, the phenology of parkland species is similar to that of cultivated plants. Several species do, however, behave as evergreens and an all-species estimation could be obtained, or images obtained at distinct times depending on species phenology. Additional experiments on preferred dates for obtaining images would be desirable.

Studies at the village level benefit from several scales of observation. In Dossi and Watinoma, Burkina Faso, aerial photographs taken at 1:50 000 were instrumental in drawing the map of morphological and land-use units, and in quantifying the percentage of land covered with parklands in villages (Depommier *et al.*, 1996). The number of trees and density variations were, however, difficult to assess. The use of satellite images resulted in a more precise land form and land use map. For parkland characterization, aerial photographs at the scale of 1:4 200 were found to be the most effective tool. Stereoscopic interpretation permitted the identification of small trees and species, and overall boundaries of field blocks as well as erosion control measures. Nevertheless, decisions by individual farmers regarding parkland management (density, composition, tree-based techniques) can only be captured at the level of the field or field section (Boffa, 1995). Field boundaries can be delimited on aerial photographs but often need to be accurately detailed through ground truthing. Large amounts of data on parkland tree characteristics, field management and socio-economic farm variables can then be stored and correlated in geographical information systems to yield a variety of thematic analyses.

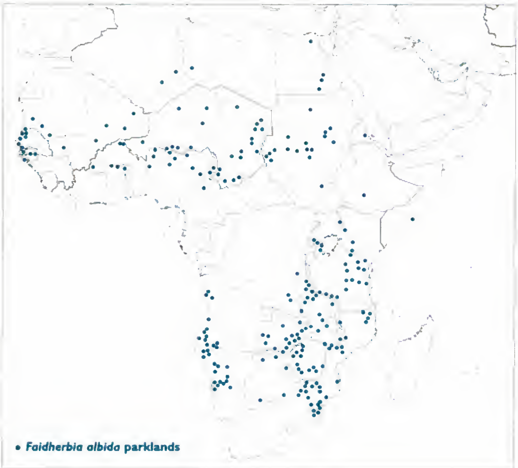
Faidherbia albida

Faidherbia albida parklands occur throughout the Sahel and Sudan zones of West Africa, as well as in eastern and southern Africa where it is strongly associated with alluvial soils along perennial or seasonal watercourses. In West Africa, *F. albida* still shows a preference for alluvial soils but occurs widely as a result of human activities on deep light sands or sandy clays. The African distribution of the species and the two geographical races identified by Brenan are shown in Figure 1.2 below. Because of its unusual characteristic of reverse foliation (i.e. bearing leaves during the hot dry season), it is water-demanding and has a deep fast-growing taproot to reach the aquifer. It occurs in areas with between 500 and 800 mm rainfall and is also found on lateritic soils where it can reach the water table through an opening in the shallow indurated pan. It also makes incursions into the northern Sahel and Sahara in moist sites or areas with a good water table (CTFT, 1988; Wickens, 1969).

Faidherbia albida, as a parkland species, is present in virtually all of Senegal (Fig. 1.3) from the Atlantic coast to the Falémé river and from the Senegal river to the Guinea Bissau border (Giffard, 1964). A highly integrated form of the *F. albida* parkland system among the Sérer in Senegal is described in depth by Pélissier (1953, 1966). This system is also present among the Wolof (Seyler, 1993) and the Mandingue of Casamance (CTFT, 1988). *F. albida* parklands are most common in the western part of the country on sandy soils within the Thiès-Louga-Kaolack triangle (Portères, 1952; Seyler, 1993; Sall 1996). In Guinea Bissau, they occur among the Brame and Mandjak ethnic groups (Pélissier, 1980a). In Mali, they extend over an estimated area of 8 780 km², or 17 percent of the country's total estimated parkland area. They are located in the rainfall range between 500 and 1 400 mm in the areas of Gondo-Mondoro, the Bandiagara-Hombori, Koutiala, and Mandingue Plateaux, the Central Niger Delta and Hod (Diallo, 1988, cited in Cissé, 1995). In terms of density and size, particularly outstanding *F. albida* parklands are found in the Dembéré-Douentza valley and extending into the Seno plain (Gallais, 1965), while Pageard (1971) reported the occurrence of well developed *F. albida* parklands in the Niger Valley between Bamako and Mopti, and particularly around Segou. A description of those in the inland Niger Delta is also available (Gallais, 1967).

The most dense and well developed *F. albida* parklands in Burkina Faso are seen among ethnic groups located near to the

Fig. 1.2 Distribution of *Faidherbia albida* (Source: adapted from Wickens, 1969)



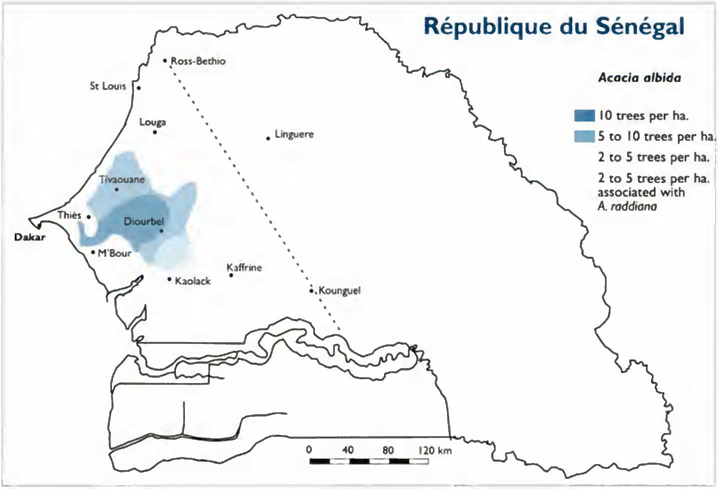


Fig. 1.3 Densities of *Faidherbia albida* in western Senegal (Source: after Portères, 1952, in Giffard, 1964)

Bambara, Dogon and sedentarized Peul cultivators who have a strong *F. albida* tradition (Pageard, 1971). The *F. albida* parkland system is dominant in the Bwa and Samo regions extending to the Senoufo, Lobi, Dagara, Birifor and northern Côte d'Ivoire regions. It is also well represented in Bissa country and in Yatenga as practised by the Mossi, though most of the Mossi Plateau is *Vitellaria*-dominated. It is found only in small, scattered areas in the Southeast and is rare in eastern Burkina Faso. In S.J. Ouédraogo's (1995) parkland classification, *F. albida* is represented in parklands throughout the country except for the extreme Southwest. For instance, he reported their existence around Markoye, Oursi, and Dori in the North, in Kokologo on the Central Plateau, and in Dossi and Boni in the West. Pure stands are reported in the Bulkiemdé Province west of the capital (Yélémou *et al.*, 1993).

In northern Côte d'Ivoire, a parkland system including *F. albida* has been described in Dolekaha. This is one of the most southern areas of *F. albida* parklands described so far (Bernard *et al.*, 1995).

In Niger, *F. albida* parklands are limited to the South and Southwest. Well-known examples are the highly stocked and permanently cultivated parklands in the '3M' (Matameye, Myrriah and Magaria) region, resulting from the enforced protection of the species during the rule of Tanimoun, Sultan of Zinder (Montagne, 1986; CTFT, 1988). References to *F. albida* parklands in southern Niger also include the zone between Damergou (Tanout) and the Nigerian border (Bertrand, 1991), and Madaroumfa next to Maradi (Montagne, 1996). In the Southwest, *F. albida* parklands occur in Tilly near Sadoré and in Guilleny (Maï Moussa *et al.*, 1993), as well as in the Dosso Department between the Dallol Bosso and the Dallol Maouri

(Montagne, 1984). *Faidherbia albida* densities in parklands in the Dosso Department are lower than in the Zinder area (Montagne, 1996).

In Nigeria, *F. albida* is an important farm tree throughout the savanna zone where rainfall is above 1 000 mm (Sanusi, 1993). An early reference was made to *F. albida* along with *Balanites, Borassus, Khaya, Anogeissus* and *Ziziphus* species in fields on the hillsides of the northern Mandara mountains in the Northeast (White, 1941), and the terraced *F. albida* system was described later by Hallaire (1976). *F. albida* is also present in *acha* (*Digitaria exilis* Stapf) and millet fields of the Biron group on the Jos Plateau in association with the cattle of Fulani herders (Gosden, 1978, cited in Miehe, 1986), as well as in the North among Hausa farmers (CTFT, 1988). Further east in northern Cameroon, a strong tradition of *F. albida* parklands has survived among the Toupouri and Massa (Seignobos, 1982). Stands are densest in the highly populated zones around Golompui and

Table 1.3 Densities of Faidherbia albida in agroforestry parklands

Country	Region, ethnic group, village	Density (trees/ha)	Source
Burkina Faso	Bam province, Mossi, Watinoma village	7-45 (all species 21-55)	Depommier et al. (1992)
	Houet province, village of Dossi	3-30, mean=6 (all species mean=9)	Depommier and Detienne (1996)
	Yatenga, village of Tugu	4	Marchal (1980)
	Passoré Province, village of Petit Samba	4.5	Gijsbers et al. (1994)
	Bulkiemdé province, 16 villages	0.8	Yélémou et al. (1993)
	Bulkiemdé, 5 villages with highest density	9-14	Yélémou et al. (1993)
Cameroon	North, village of Tokombéré, 38 ha	5.4 (all species 6.7)	Libert & Eyog-Matig (1996)
	North, 30 samples around Maroua	total 23 (13.5% cover)	Triboulet (1996)
	North, east of Maroua, Balaza Alkali area	8-35 (all species 14-47)	Seignobos (1982)
Côte d'Ivoire	North, village of Dolékaha	3.5 (all species 13)	Bernard et al. (1996)
Ethiopia	ILCA exp. station, Debre Zeit, 1850m	a.s.l. 6.5	Kamara and Haque (1992)
	Hararghe highlands, Alemaya area	1-10	Poschen, 1986
	Hararghe highlands, east of Harar town	20 (>33% cover)	Poschen, 1986
Mali	Inner delta, upland villages	5-10 (<5% cover)	Gallais (1967)
	Inner delta, bottomland villages	20-25 (15-20% cover)	Gallais (1967)
	Dogon, Dembéré-Douentza valley	40-50 (all species 50-62)	Gallais (1965)
Niger	Matameye-Myrriah-Magaria area	100-120 (100% cover)	CTFT (1988)
	Tilly village on Niger River next to Sadoré	13	Mai Moussa et al. (1993)
	Guilleny village, 80 km from Niamey	47	Mai Moussa et al. (1993)
	Dosso area, 10 villages in Tibiri-Dogon Doutchi	29 (all species 72)	Montagne (1996)
Senegal	Cayor region, Wolof, town of Louga	1-10	Portères (1952)
	Region of Baol, Serer	2-10	Portères (1952)
	Serer, oldest settlements	50	Pélissier (1966)
	Serer, recent settlements	26	Pélissier (1966)
	Serer, Bambey area	16	Charreau and Vidal (1965)
	Serer, village of Sob (550 ha)	4.5 (all species 8.3)	Lericollais (1989)
	Peanut Basin, 72 villages	9	Seyler (1993)
Sudan	Jebel Marra highlands, Koronga area	7-15 (all species 9-19)	Miehe (1986)
	Jebel Marra area	20	Miehe (1986)
	Jebel Marra, river terraces	74	Radwanski and Wickens (1967)
	Jebel Marra area	12-90	FAO (1968)

Datcheka and some stands can also be observed around settlements among the Dowayo in the vicinity of Poli. *Faidherbia* parklands were widespread in the Diamaré area before their destruction during the Fulbe conquest in the nineteenth century. They are gaining ground again due to an increase in human population density (Seignobos, 1982). *F. albida* has the highest representation among the tree species present in 30 parkland samples within 30 km of Maroua (Triboulet, 1996). In Chad, relics of *F. albida* parklands are found among the Sara around the town of Koumra and well developed *Acacia* communities exist among the Kera around Fianga Lake (Seignobos, 1982).

Elsewhere in Africa *F. albida* parklands also occur in Sudan in the Fur farmlands in the Jebel Marra Highlands of Western Darfur (Miehe, 1986). The species dominates montane habitats between 1 800 and 2 300 metres above sea level, but *F. albida* parklands are also conspicuous in the Wadi Azoum alluvial system in the pediplains west of the Jebel Marra massif (Radwanski and Wickens, 1967). *Faidherbia albida* occurs along with other tree species in fields in the Nuba mountains in southern Kordofan province (Miehe, 1986). It is widespread in the Hararghe highlands of eastern Ethiopia (Poschen, 1986) and is reported further west around the town of Debre Zeit (Kamara and Haque, 1992), as well as associated with *Cordia abyssinica* in the Rift Valley among the Galla and Arussi groups (Miehe, 1986). *Faidherbia albida* also used to be maintained in arable areas of the Upper Jordan valley (Karschon, 1961).

Some *F. albida* parklands are found in Southern Africa. They have been studied in Tanzania (Fernandes *et al.*, 1984; Okorio and Maghembe, 1994; Wickens, 1969), in Malawi's Lakeshore plain and upland central region (Saka *et al.*, 1994; Rhoades, 1995), and in Zimbabwe (Campbell *et al.*, 1991).

Reported *F. albida* densities in parklands throughout its zone of distribution are listed in Table 1.3. Compilations of information on various aspects of the species are presented in van den Beldt (1992), CTFT (1988) and Wickens (1969), among other sources.

Fig. 1.4 Flowering *Vitellaria paradoxa*, Sankpala, Ghana *P. Lovett*

Vitellaria paradoxa

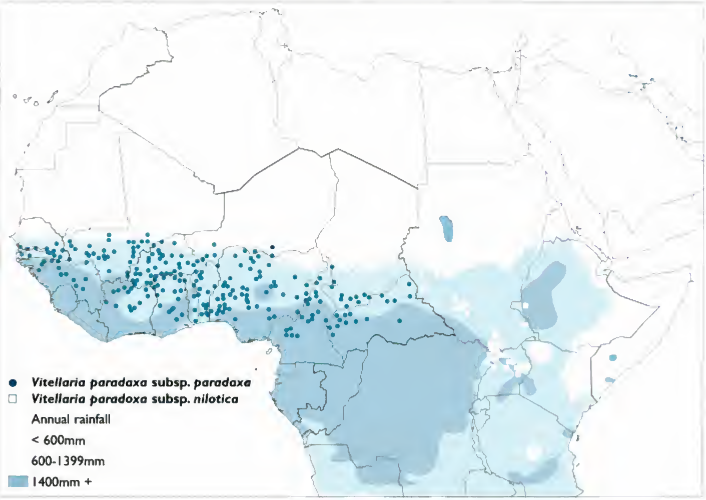
Vitellaria paradoxa is probably the most common parkland species in semi-arid West Africa (Breman and Kessler, 1995). There are two subspecies in the genus, the subspecies *paradoxa* occurring from Senegal to the Central African Republic and the subspecies *nilotica* in southern Sudan and Ethiopia, Uganda and northeast Zaire (see Fig. 1.4). *V. paradoxa* is generally found in wooded grassland and farmland within the rainfall zone of 600 to 1 400 mm, annual potential evapotranspiration from 1 400 to 2 300 mm, and a dry period of 5 to 7 months. It preferentially grows on colluvial soils of reasonable depth (> 30 cm above parent rock or indurated layer), free drainage, and a

predominantly sandy topsoil texture (Hall *et al.*, 1996). Like other parkland species, its distribution has also been shaped by human influence.

A few estimates of the surface area occupied by *Vitellaria* species are available for Mali. Ruyssen (1957) has *Vitellaria* parklands occurring south of the line going through Bafoulabe, Segou and Bandiagara with an estimated distribution area of 19.4 million ha, revised to 22.9 million ha by Maïga (1990, cited in Cissé, 1995). Ruyssen (1957) estimated that 943 000 ha had *Vitellaria* as a significant tree component on land cultivated annually with rainfed crops. Based on a five-year rotation (one cropping and four fallow seasons), the area of productive *Vitellaria* parkland was estimated at 4.7 million ha. Clamagirand and Bruffaerts (1983, cited in Raison, 1988) state that at least 3.6 million ha in Mali have *Vitellaria* with a density of over 40 trees/ha. The species was represented in parklands covering 68 percent of the 415 700 ha middle Bani-Niger river basin mapped by ICRAF (1996).

Vitellaria parklands occur throughout Burkina Faso south of 14° latitude (S.J. Ouédraogo, 1995). In Bulkiemdé Province, *Vitellaria* has the highest density among parkland species (Yélémou *et al.*, 1993). In Niger, the distribution is irregular and linked to human activities (Ounteni, 1998), with *Vitellaria* occurring in the south central and southwestern regions of the country (Hall *et al.*, 1996). *Vitellaria paradoxa* and *Parkia biglobosa* are the most common indigenous parkland species in northern Ghana (Rudat *et al.*, 1996) and spread through northern Togo and Benin where they have been studied in the Bassila and Parakou areas (Schreckenberg, 1996; Agbahungba and Depommier, 1989). They are also referred to in the north of Côte d'Ivoire (Bernard *et al.*, 1995; Louppe and Ouattara, 1996).

Fig. 1.5 Distribution of *Vitellaria paradoxa* subsp. *paradoxa* and *V. paradoxa* subsp. *nilotica* in relation to mean annual rainfall. (Source: Hall et *al.*, 1996)



In Nigeria, *Vitellaria* parklands cover large areas. They were observed around Birnin Kebbi in the Northwest, south of Bida (southwest of Kaduna) in an area of old Nupe settlements (Pullan, 1974) and west of the Mandara mountains in the Northeast (Seignobos, 1982). *Vitellaria paradoxa* was cited among the most important farm trees during farmer interviews around the towns of Saki, Ilorin, Minna, Jos, Kaduna and Kano (Teklehaimanot *et al.*, 1995). In northern Cameroon it is represented in many bushfallow communities outside *F. albida* parkland zones, in Toupouri country for example, but there are few well-developed *Vitellaria* parklands except on terraces of the Benoue valley west of Garoua (Seignobos, 1982). In southern Chad, there are large expanses of *Vitellaria* parklands (Seignobos, 1982) with tree densities higher than in *F. albida* parklands. References are also made to *Vitellaria* parklands among the Ngambay (area of Moundou in the Southwest) and around Koumra (west of Sarh, northern part of Sara country) mixed with *F. albida* (Seignobos, 1982). *Vitellaria* also dominates parklands south of Domo Dambali in Moussey country.

In Ouham province in the northwest of the Central African Republic, agriculture is traditionally practised under the parkland cover of *V. paradoxa* associated with *P. biglobosa* in high densities (Depommier and Fernandes, 1985). Further east, *V. paradoxa* subsp. *nilotica* is reported in fields in northern Uganda, where its density is highest in Otuke county in Lira district (Masters and Puga, 1994). Reported *V. paradoxa* densities in parklands throughout their distribution zones are listed in Table 1.4. Additional information on the species can be found in several monographs (Hall *et al.*, 1996; Bonkoungou, 1987).

Table 1.4 Densities of Vitellaria paradoxa in agroforestry parklands

Country	Region, ethnic group, village	Density (trees/ha)	Source
Benin	Central, Borgou area between Parakou and N'Dali	30-60 (all species 50-100)	Agbahungba and Depommier (1989)
	Central, Bassila area, 3 villages	25 (all species 63)	Schreckenberg (1996)
Burkina Faso	Zoundweogo Province, village of Thiougou	19 (all species 27)	Boffa (1995)
	Passoré Province, village of Petit Samba	12	Gijsbers *et al.* (1994)
	Mouhoun Province, village of Oula	5-10	Kessler (1992)
	Bulkiemdé province, 8 villages	6.2	Yélémou *et al.* (1993)
Central African Republic	Northwest, Ouham area	30-70 0) (all species 50-10	Depommier and Fernandes (1985)
Chad	South	30	Groene (1966) cited in Seignobos (1982)
Côte d'Ivoire	North, village of Dolékaha	2 (all species 13)	Bernard *et al.* (1996)
	North, Korhogo area	15-30	Ruyssen (1957)
Ghana	Ajura-Atebobo	83	Chipp (1927) cited in Hall *et al.* (1996)
Mali	Villages 120 km north of Bamako	4.2 (all species 3-14, mean=7)	Ohler (1985)
	Southeast, Sikasso area	8	Kater *et al.* (1992)
	South, villages of Pourou, Guetela, N'Tossoni	8-12	Bagnoud *et al.* (1995b)
Uganda	Villages of Adwari, North Adwari, Orum and Okwang, Lira District		4-18 Masters (1992)

Parkia biglobosa

Parkia biglobosa is often found in parklands in association with *V. paradoxa*. This species is mostly present in areas with between 800 and 1 500 mm of rainfall, and 1 400 and 2 100 mm of potential evapotranspiration, and is generally associated with a dry season of 5-7 months. Its range is similar to that of *V. paradoxa* but extends further south. *Parkia biglobosa* typically occurs on mid-toposequence positions on deep soils and sometimes, through farmer protection, on well-drained soils in floodplains and riparian sites. It is absent from depressions where soil drainage is impeded (Hall *et al.*, 1997). The species naturally occurs in the dry forests of the Sudano-Guinean zones where it is associated with *Pterocarpus erinaceus* (Sall, 1996). In Senegal, it is found on various soils in the Sine, Cayor, Laghem, Saloum, Tambacounda and Niololo Koba areas, but not in the North (Sall, 1996). *Parkia biglobosa* in parklands is found in the southern tip of Gaya in Niger (Ounteni, 1998), in south Mali (Kater *et al.*, 1992; Bagnoud *et al.*, 1995b), throughout Burkina Faso except north of the south Sahel zone (Teklehaimanot *et al.*, 1997), in northern Côte d'Ivoire (Bernard *et al.*, 1995), northern Ghana (Rudat *et al.*, 1996), northern Togo among the Kabre (Enjalbert, 1956), and the northern half of Benin (Schreckenberg, 1996; Agbahungba and Depommier, 1989). In Nigeria, *Parkia* genus was reported in fields in Bomo, north of Zaria (Pullan, 1974), and was studied in sixteen sites throughout the lowland forest zone up to the Sudan savanna zone (Teklehaimanot *et al.*, 1996b). Pure stands were also observed in northern Cameroon (Seignobos, 1982) and the species pervades parklands in the Ouham province of northwestern Central African Republic (Depommier and Fernandes, 1985). Information regarding the taxonomy, biology, ecology, management, and uses has recently been compiled by Hall *et al.* (1997). Reported *P. biglobosa* densities in parklands throughout their distribution zones are listed in Table 1.5.

Fig. 1.6 Distribution of *Parkia biglobosa* in relation to mean annual rainfall (Source: Hall *et al.*, 1997)

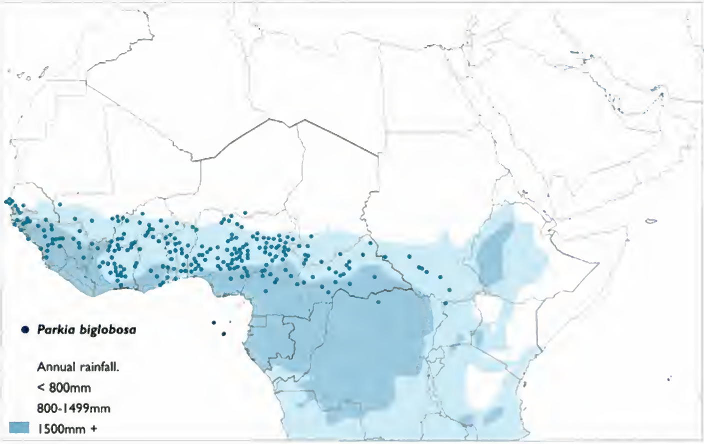


Table 1.5 Densities of *Parkia biglobosa* in agroforestry parklands

Country	Region, ethnic group, village	Density (trees/ha)	Source
Benin	South Borgou area	5-10 (all species 50-100)	Agbahungba and Depommier (1989)
	Central, Bassila area, 3 villages	2 (all species 63)	Schreckenberg (1996)
Burkina Faso	Mouhoun Province, village of Oula	2	Kessler (1992)
	Bulkiemdé province, 8 villages	0.8	Yélémou *et al.* (1993)
	Areas of Ouagadougou and Fada, 2 sites each	2-5	Teklehaimanot *et al.* (1997)
	Areas of Bobo and Banfora, 2 sites each	9-21	Teklehaimanot *et al.* (1997)
Central African Republic	Northwest part, Ouham area	15-40 (all species 50-100)	Depommier and Fernandes (1985)
Côte d'Ivoire	North, village of Dolékaha	3.6 (all species 13)	Bernard *et al.* (1996)
Mali	Southeast, Sikasso area	8	Kater *et al.* (1992)
	South, villages of Pourou, Guetela, N'Tossoni	1-5	Bagnoud *et al.* (1995b)
Nigeria	Zaria area	1-14	Pullan (1974)
	Lowland forest zone, areas of Eruwa and Nsukka	7.4	Teklehaimanot *et al.* (1997)
	Derived forest zone, areas of Ilorin and Jos	10.9	Teklehaimanot *et al.* (1997)
	Guinea forest zone, areas of Kaduna and Kontagora	10.2	Teklehaimanot *et al.* (1997)
	Sudan forest zone, areas of Kano	13.5	Teklehaimanot *et al.* (1997)

Other important parkland species

Overall, *F. albida*, *V. paradoxa* and *P. biglobosa* are probably the most widespread parkland species in the Sahel and Sudan zones of Africa. This explains their predominance in the existing literature. However, this should not conceal the importance of a large number of other parkland species, whose representation may be more restricted geographically but which may, on a local scale, be more abundant and more economically valuable. It is worth emphasizing that one of the major assets of agroforestry parklands is their biological (and genetic) diversity. This implies a wide diversity of uses and applications with significant economic value and a variety of management techniques and objectives (both discussed in later chapters).

The baobab (*Adansonia digitata*) is one of the best known and often reported tree species in semi-arid Africa, due to its large size and associated mythical and spiritual powers. *Adansonia* parklands throughout the zone are associated with both old and recent settlements. The species is characteristic of plant communities of the Sudano-Zambezian lowlands with 200-800 mm annual rainfall, but it has extended into higher rainfall areas, possibly with human assistance (Wickens, 1982). It is very common in the intensively managed and permanently cultivated fields around residential compounds. High densities are present in western Senegal around Dakar, Bargny (densest stands) and Thies, north of the Gambia river between Kaolack and Tambacounda, as well as in the Kedougou area in the Southeast (Sall, 1996), and were used as a defensive barrier against attacks by men on horseback (Baumer, 1994). *Adansonia* parklands are found in Burkina Faso's Yatenga and Bam provinces (S.J. Ouédraogo, 1995), and the species is represented in parklands on 12 percent of the middle Bani-Niger river basin in Mali (ICRAF, 1996). It occurs on old settlement sites in parklands of the southern Mandara, in northwestern Nigeria (Seignobos, 1982) and in northern Togo among the Kabre (Enjalbert, 1956). Additional review information on the species, including its distribution and ecology by regions, is provided in Wickens (1982).

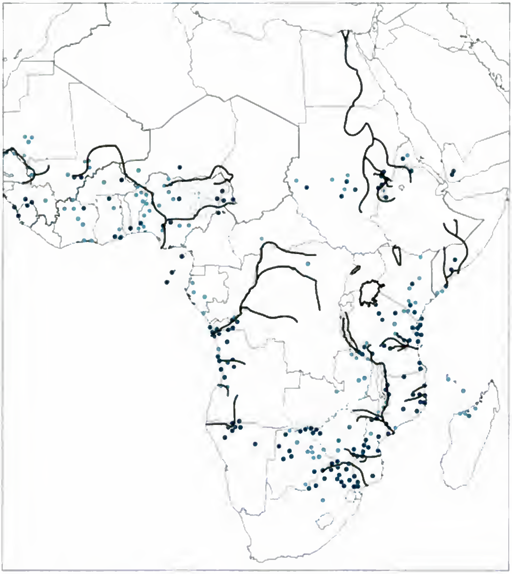


Fig. 1.7 Distribution of *Adansonia digitata* in Africa and neighbouring areas
Key:

- **1 Distribution based on Herbarium and flora records;**
- **2 Specimens known to be cultivated or introduced;**
- **3 Distribution based on published and unpublished photographs;**
- **4 Distribution based on the Kew 'Baobab Survey' information;**
- **5 Records obtained from travel literature, maps etc.**

(Source: Wickens, 1982)

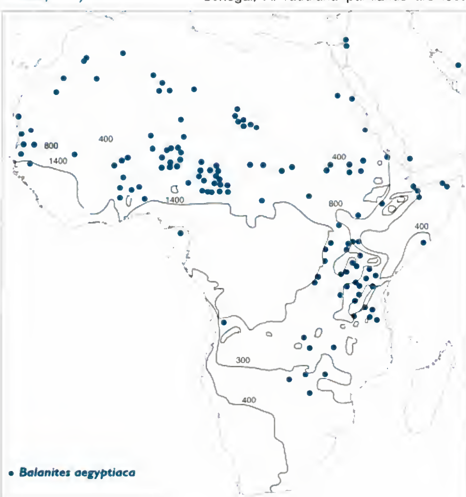
Fig. 1.8 *Adansonia digitata* parklands, Senegal
R. Faidutti

Borassus aethiopum, or fan palm (*rônier* in French), also has a wide distribution. It is found on a variety of soil types but demands a high water holding capacity and shallow groundwater tables. Its development is favoured by fertile and weeded soils as found in parklands (Niang, 1975; Weber and Hoskins, 1983; Cassou *et al.*, 1997). Among other places, it occurs along all the major rivers and other water bodies of the Sahel. According to Pélissier (1980a), the most beautiful stands are in villages around the mouth of the Soungrougou river (Ziguinchor and Koida), Casamance in Senegal. Other stands exist in the North in the Goumel forest next to Dagana, in the Northeast in the Matam *département*, in the Southwest near Tabacounda

and on the Gambia river, as well as west around the towns of Thiès, Dakar and Fatick. Very high densities of 50-100 and 115 trees/ha in almost pure stands were reported in the Leolgeou area in Mali (Gallais, 1965) and Wolokonto, Burkina Faso. The species forms one of the ten parkland types classified in Mali (Cissé, 1995). In Burkina Faso, they are most common in the southwestern provinces of Bobo-Dioulasso and Banfora in village or compound fields (S.J. Ouédraogo, 1995). In Niger, *B. aethiopum* occurs in six major populations estimated at 27 000 ha in the Dallol Maouri, Gaya Department, and 3 000 ha along the Niger river and on Leté island (Ounteni, 1998).

The species occurs in northern Ghana associated with *F. albida*. This combination is also found in Nigeria near Foggo, southwest of Azare, an area of Hausa and Fulani settlement (Pullan, 1974), and in northern Cameroon around Mboum settlements in the Guidar region (Seignobos, 1982). *Borassus aethiopum* is also observed in the North Cameroon inlet of Chad between and along the Logone and Chari river valleys, for example among the southern Kotoko and Mousgoum people around Goffa, Holom, Marmay and Pouss, and among the Massa in Ziguey, Goufka, Domo, Bosgoye, Geme, Nahaide and Dana (Seignobos, 1982). In Chad, the *Borassus* area extends east and southeast from the Logone river along the southern fringe of the Baguirmi region going through the towns of Logone Gana, Morno, Ngam (Kwang group) to the Sarwa region and even into the Day area (Seignobos, 1982).

Fig. 1.9 Distribution of *Balanites aegyptiaca* in relation to mean annual rainfall. The 400, 800 and 1400 mm isohyets are shown. The hatched area is the 'main range'. (Source: Hall and Walker, 1991)



Dominant species in the Sahelian (northern) parklands include *Acacia raddiana* (syn. *Acacia tortilis*), *Acacia senegal*, *Balanites aegyptiaca* and *Hyphaene thebaica*. In Senegal, *A. raddiana* parklands are located throughout the North (Sall, 1996). Trochain (1940) also mentioned mature *A. raddiana* trees in groundnut fields in the Sahelian part of the country. *Acacia raddiana* is found in the Sahel zones of Mali (Cissé, 1995) and Burkina Faso, sometimes in pure stands (S.J. Ouédraogo, 1995). The species occurs almost exclusively in cultivated or agro-pastoral areas, in contrast to *A. senegal* which is characteristic of rangelands in West Africa. In Sudan, virtually pure stands of *A. senegal* are systematically rotated for crop and fallow/gum production and are sometimes referred to as 'gum gardens' (Seif El Din, 1981; Jamal and Huntsinger, 1993).

Balanites aegyptiaca is a spiny, fairly short tree, occurring most frequently on the 400-800 mm rainfall zone. The species avoids shallow and gravelly soils and prefers deep sands, sandy clay loams or clays in lowlands. As a shrub, it is an important species on aeolian sands in the Sahel (Hall and Walker, 1991). It is associated with *A. raddiana* in northern Senegal (Nizinski and Grouzis, 1991; Sall,

1996), Mali (Cissé, 1995) and Burkina Faso (S.J. Ouédraogo, 1995). It is also well adapted to the climatic conditions prevailing in Niger where it is widespread (Ounteni, 1998). It is the most frequent species in parklands in Léré, Koro *arrondissement* (district) in the Fifth Region of Mali (PRSPR, 1993), and is reported in *Vitellaria*-dominated parklands in Birnin Kebbi, northwestern Nigeria (Pullan, 1974). Additional data on the species are available in Hall and Walker (1991).

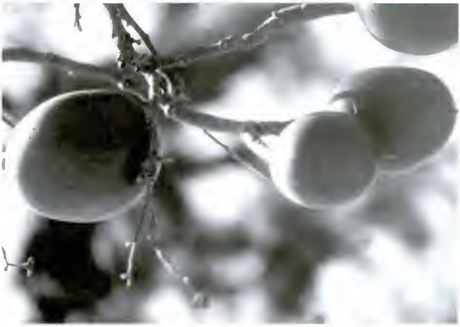
Hyphaene thebaica, or dum palm, is another economically significant Sahelian species which is easily recognized by its dichotomous branching habit. It occurs in the Sahelian and Sudano-Sahelian zones with 200 to 600 mm rainfall, even extending to the southern edge of the Sahara, generally on light soils with shallow aquifers, in dune depressions or gallery forests but not on rocky soils (Raison, 1988; von Maydell, 1983). It is mentioned in parklands in the Ferlo river valley, Senegal (Freudenberger, 1993b), in the Leolgeou area, Mali (Gallais, 1967), in Tilly, southwestern Niger (Maï Moussa *et al.*, 1993) and in many *dallol* and *goulbi* valleys and along the Niger river (Ounteni, 1998). It also occurs in northern Nigeria (Sanusi, 1993) and is characteristic of parklands in the southern Sahelian region of Burkina Faso (S.J. Ouédraogo, 1995).

Other important parkland species include the oil palm, *Elaeis guineensis*, found in Benin (Schreckenberg, 1996; Raison, 1988) and northern Togo (Enjalbert, 1956). The exotic species, *Azadirachta indica* (neem), has expanded widely in Sahelian countries, to the point of sometimes being considered an invasive pest (Ganaba, 1996). It thrives in the Bulkiemdé province of Burkina Faso, especially in compound fields (Yélémou *et al.*, 1993) where it is the second most common parkland species after *V. paradoxa* (Yélémou, 1993). *Prosopis africana* is a major, yet declining parkland species along the Chad-Cameroon border north of Fianga Lake and further east in Ngam in Chad (Seignobos, 1982; Bernard, 1996). It also occurs in the southern part of the Dosso and Tillabéry Departments as isolated individuals and as monospecific stands in the Matameye area, Zinder Department in southern Niger (Ounteni, 1998).

Ceiba pentandra parklands have been noted around Zaria, Nigeria (Jackson, 1970) and in northern Togo (Enjalbert, 1956). *Cordyla pinnata* (dimb) was ranked second in relative abundance after *F. albida* in Sob, Senegal (Lericollais, 1989), and after *V. paradoxa* in Mali (Ohler, 1985). It thrives in farming systems with high population density in the Sine Saloum area of Senegal because of its nutritional contribution, the kernels being used as a substitute for meat (Niang, M., 1998). *Cordia africana* dominance was reported in fields devoid of *F. albida* in the Alemaya area, Ethiopia (Poschen, 1986).

The list of species occurring in parklands reviewed so far is by no means exhaustive. The following, among many others, can be added: *Sclerocarya birrea*, *Parinari macrophylla*, *Cola cordifolia*, *Anogeissus leiocarpus*, *Bombax costatum*, *Tamarindus indica*, *Sterculia setigera*, *Ziziphus mauritiana*, *Lannea microcarpum*, *Lannea acida*, *Pterocarpus erinaceus*,

Fig. 1.10 ***Cordyla pinnata* fruit, Nioro du Rip, Senegal**
P. Danthu



Diospyros mespiliformis, Detarium microcarpum, Combretum glutinosum, Celtis integrifolia, Piliostigma reticulatum, Cordia myxa, Khaya senegalensis, Blighia sapida, Tectona grandis.

Factors used in establishing parkland typologies

As noted earlier, savanna landscapes have evolved under the influence of natural processes such as fire and grazing. In contrast, parklands reflect deliberate human manipulation of trees in agricultural production systems. Various classification systems attempt to capture regional and local variations in parkland structure and composition according to factors such as the degree of human intervention, their main functional uses, their physical structure, and their reflection of the different natural resource management systems of diverse ethnic groups.

Degree of human intervention

Geographers first classified parklands in relation to the degree of human intervention that contributed to their formation, an approach which was particularly useful in revealing gradations of management intensity and giving them a broad, inclusive representation among human-manipulated vegetation types. Categories first established by Pélissier (1964), and later adapted by Seignobos (1982) and Raison (1988), are presented below and an attempt made to examine how effective they are in reflecting actual and significant field realities.

The least elaborate and most transient type is 'residual' parklands. Species that are either useful or too hard to cut are left after clearing, but their density does not necessarily reflect the importance of their use. Species richness is relatively high in this type and is bound to decline with further selection. These parklands will only persist where low population density allows long time intervals between clearings. *Cordyla pinnata* parklands observed by Pélissier (1980a) between Saloum and Gambia in Senegal are one example. They are primarily used for grazing and harvesting of tree fruits (Baumer, 1994).

The second type develops with conditions created by 'clearing'. Such parklands are generally composed of shade-intolerant species, released after clearing, and species which become dominant due to their ability to regenerate quickly from root-suckers (Seignobos, 1982). Typical species include some acacias and *Prosopis africana*, which benefit crop production and provide excellent fodder. *Prosopis africana*, however, also persists in old parklands (Bernard, 1996). *Elaeis* is a similar case (Pélissier, 1964). The two kinds of parkland presented above are often short-lived, but their recognition may be useful to situate their current stage and potential for evolution into a more elaborate and stable type.

Karité and néré parklands have been deliberately protected in the field. They reflect old, stable and relatively dense settlements.

'Selected' parklands are composed of trees which were part of the initial vegetation and have been deliberately protected in fields owing to their various uses including food, fodder or soil fertility. Their composition and density correspond to family and community needs. They reflect old, stable and relatively dense settlements as well as landscapes more deeply influenced by human beings than the previous two types. Classic examples are the *karité* (*Vitellaria paradoxa*) and *néré* (*Parkia biglobosa*) parklands. Given the slow growth rate of *Vitellaria*, such parklands indicate a certain degree of permanence. Systems based on the fan palm, *Borassus aethiopum* (source of palm wine and seedlings eaten during

famines), and to some degree the oil palm, *Elaeis guineensis*, are other examples of selected parklands.

Fig. 1.11 ***Borassus aethiopum*** **parkland, Senegal**
R. Faidutti

Quantitative evidence of differences in tree density and species composition in fields as compared to the original savanna vegetation illustrates the impact of human selection on parkland formation. Farmers tend to reduce the total number of stems and species and favour preferred species. In *Vitellaria* and *Parkia* parklands of southern Burkina Faso, a third of the species found in uncultivated woodland savanna were not found in adjacent agricultural fields, while nine out of ten woody individuals were thinned during clearing and cultivation. At the same time, the relative abundance of *Vitellaria* had increased five times from 16 to 83 percent, and that of *Parkia* nine times from 0.4 to 3.5 percent (Boffa, 1995). Similarly in Benin, *V. paradoxa* and *P. biglobosa* represented 10.6 and 0.7 percent of trees in their original savanna vegetation and 39.2 and 3.6 percent in fields, a 3.7 and 5.4 fold increase respectively (Schreckenberg, 1996).

The fourth type, 'constructed' parklands, is made up of species which may not always be present in the initial vegetation, at least not in the densities observed after farmer selection. They are more elaborate as trees are not only protected but also pruned and tended in order to reach large height and crown dimensions. The best example is that of *F. albida* which is naturally bushy but which will develop into tall trees when pruned early on. This type has also been called substitution parkland in the case of *F. albida* (Seignobos, 1982), because the species, which can be absent from climax communities, may partially or completely replace spontaneous vegetation (Pélissier, 1980b).

The fifth type of parkland displays species disseminated by people in a type of 'proto-arboriculture' (Seignobos, 1982). Such parklands are strongly linked to settlements. For example, the baobab, *Adansonia digitata*, the fruits, leaves and bark of which are systematically gathered, is a familiar sight in Sahelian villages. Years after settlements relocate, its presence may still indicate areas used for cultivation. *Borassus aethiopum* is another such species. Among others, it was associated with the Baïnouk people and is found along their migration paths from Senegal to north Cameroon (Pélissier, 1980b).

Finally, 'planted' parklands have the highest degree of human intervention and may more appropriately be referred to as intercropped orchards. Such is the case, for instance, of orchards of mango trees interplanted with food crops. However, whether such stands of specially planted trees qualify as parklands is debatable (Raison, 1988).

The lack of clear definitional boundaries tends to make the different parkland types less operational than desired. Selected and constructed parklands can overlap as in the case of *Vitellaria* and *Parkia* parklands. Both are selected from the pre-existing vegetation, but they are also constructed through farmer management. As

suggested by the above data, tree size and relative abundance are greatly enhanced through the selective process and their density in parklands may also be increased through fallow enrichment, transplanting or planting. The same can be said of the *Acacia senegal* (and *Acacia laeta*) parklands of Sudan, often called gum gardens[2]. Present in the original vegetation, they are selected and constructed through various cycles of cultivation consisting of coppicing, fallow and gum collection. As parkland trees become more valuable and are managed more intensively by manuring, trimming and pruning practices, the distinction between selected and constructed parklands will probably become less pronounced.

Similarly, distinctions between constructed, proto-arboricultural and planted parklands can appear artificial. For example, in areas where land use becomes sedentary, *A. digitata* parklands may be considered to be constructed rather than products of proto-arboriculture. The case of *Azadirachta indica*, which is both planted and disseminated by birds, encompasses all three categories. Similarly, the notion of substitution of the original vegetation by one species, as in *F. albida* parklands, is at least potentially present in the (trans-) planting of parkland species. There is no clear consensus on the inclusion of intercropped orchards (mango, citrus, palm) in the parkland family, yet the 'artificialization' of tree cover in parklands is likely to become more pronounced as research and development efforts give increasing recognition to trees in these systems. One may speculate that the dissemination and planting of domesticated parkland trees will further challenge the available classification and may increasingly divert attention from categories for whole systems towards a parkland mosaic of niches specific to particular species. Clearly, there are opportunities for refining and operationalizing parkland classifications.

Functional classification

By allowing certain trees to persist in their fields, local populations have shaped the tree component of their farmland to fulfil specific needs. Among the most impressive and probably insufficiently recognized characteristics of agroforestry parklands are the diversity of tree species they contain and the variety of products and uses they generate. This has led researchers to develop functional classifications for parklands as in the one adapted from Seignobos (1982) in Table 1.6. Some of these categories, such as the use of tree fibre for clothing, appear less relevant today. In addition to the productive roles presented in Table 1.6, trees are maintained in fields for less obvious purposes, such as the provision of shade, fodder storage (crop residues like cereal stalks and cowpea stems stored in branches of tall trees), and a vast array of medicinal products. Chapter 6 elaborates on the quantitative and qualitative diversity of parkland products and services.

Spatial analysis

As a result of habitat dispersion, land-use patterns, social groupings and defence needs, as well as economy of movement, farmland is often arranged in concentric rings around settlements in rural Africa. Management intensity levels decrease as distance from the compound increases (Morgan, 1969). In the Sudan zone of West Africa, three major concentric rings characterized by different cropping and soil management activities have been recognized (Prudencio, 1993; Sautter, 1962): (i)

[2] In contrast to the gum gardens of Sudan, *Acacia senegal* parklands in the northern fringe of West Africa would not belong in the constructed parklands category as they are less intensively managed and tend to be exclusively pastoral.

Table 1.6 Main productive functions fulfilled by agroforestry parklands

Parkland function	Examples
1. Famine food	Parkland products eaten when crops have failed. Young shoots of Borassus aethiopum eaten as vegetables; fruits and leaves of Ficus gnaphalocarpa and other Ficus species.
2. Food complement	Condiments served with staple cereals. Seeds of *Parkia biglobosa, Tamarindus indica; Adansonia digitata* and *Ceiba pentandra* leaves.
3. Fat and oil production	Butter extracted from *Vitellaria paradoxa*; oil produced from *Balanites aegyptiaca, Parinari macrophylla, Lophira alata* and *Elaeis guineensis*.
4. Soil fertility	*Faidherbia albida* and, to a lesser degree, *Prosopis africana*.
5. Wine production	The sap of *Elaeis guineensis, Borassus aethiopum* and *Hyphaene thebaica* is processed into wine.
6. Wood production	*Ziziphus* spp., *Anogeissus leiocarpus* (firewood), *Borassus aethiopum* (construction).
7. Handicrafts and clothing	*Borassus aethiopum* (baskets, hats, furniture), fibres from *Adansonia digitata, Ficus thonningii* and *Ficus glumosa*.
8. Browse	*Pterocarpus erinaceus, Pterocarpus lucens, Balanites aegyptiaca, Faidherbia albida, Acacia raddiana, Bauhinia rufescens*.

(Source: adapted from Seignobos, 1982)

a zone of home gardens or compound fields (*champs de case*), (ii) a zone of permanently cultivated village fields, and (iii) a zone of bush fields.

'Compound fields' are usually located within a 50 m radius of the compound. They are heavily fertilized with household wastes and manure produced by small livestock and fowl kept close by. Soil fertility and moisture conditions are generally higher here than on other farmland types and can support crops such as maize and red sorghum. Vegetables and other crops used daily are grown near the house for convenience.

'Village fields' extend within a ring several hundred metres wide. Depending on distance and fertility, they may be manured and can be fertilized with chemical fertilizers and permanently cultivated. In many parts of semi-arid West Africa, migrant Fulani herders arrange with local farmers to manure these fields in exchange for various benefits. In areas of high population density where land degradation has taken place, erosion control measures such as rock bunds may have been applied on these and compound fields. Farmers generally cultivate a variety of crops, such as white sorghum or millet intercropped with cowpeas and groundnuts in village fields. Cotton, tuber crops and Bambara groundnut (*Voandzeia subterranea*) may also be found.

'Bush fields' further out are where the bulk of staple crops such as sorghum, millet, cowpeas, and groundnuts (on relatively sandy soils) are cultivated. Historically, this is a zone of shifting cultivation where the area of fallow grass is much greater than that under crops (Morgan, 1969), the ratio being highly dependent on population density. In recent decades, there has been a strong tendency to shorten or eliminate fallow periods. Fertile and moist lowland areas, where farmers grow vegetable crops, rice, sorghum, etc., may occur regardless of distance from settlements.

Tree selection and conservation are closely linked to agricultural production activities over a span of years or decades. The spatial structure of parklands is influenced, therefore, by the specific management of each of the above-mentioned cultivation rings. In fact, a *terroir villageois* (village land) is often said to harbour three distinct zones of tree cover, namely a 'core' and a 'margin' with an intervening zone of 'plain parkland' (Seignobos, 1982). The core or residential zone has species with particular uses which may not be found elsewhere such as *Mangifera indica* and other fruit and shade trees, *Ficus thonningii*, *Azadirachta indica*, *Eucalyptus* spp., *Cassia siamea*, *Adansonia digitata*, *Ceiba pentandra*, *Tamarindus indica*, etc.

(Savonnet, 1959; Pullan, 1974). The plain or pure parkland zone is found on permanently or repeatedly cultivated fields and visually represents the agricultural system practised. It is usually dominated by one or a few species, such as *F. albida*, or *V. paradoxa*. In Birnin Kebbi, northwestern Nigeria, this zone is characterized by the presence of mature trees of species including *Vitellaria, Tamarindus, Vitex, Ficus* and *Balanites* (Pullan, 1974). In the Jebel Marra massif of western Sudan, the most extensive *F. albida* parklands are primarily found in limited areas of very dense and continuous habitation (Miehe, 1986). In parkland margins, a greater variety of species may be selected or selection may be less precise.

This general threefold zonation is reflected in several studies which record the different names given to each field type in local languages. For instance, among the Bwaba-Bobo-Oulé of Burkina Faso, *ka* fields around compounds, and extending 25 to 50 metres out, are heavily manured and enclosed with fences, and contain *C. pentandra*, baobab and tamarind trees (Savonnet, 1959). Outside the *ka* fields, there are *wa* fields corresponding to the area covered with *F. albida* trees in a radius of up to one kilometre. Still further out are the more intensive *ma* or bush fields, which undergo fallowing and are dotted with *V. paradoxa*, *P. biglobosa* and *Ficus* spp. Likewise, Gallais (1967) notes that the ring of permanent fields is called *so-foro* in Bambara, or *fio* by the Bwa people in the inland Niger delta region in Mali, while bush fields are called *kongodian-foro* and *mwese* respectively by these two ethnic groups. In Wolokonto, Burkina Faso, compound gardens include mango, citrus and cashew trees, while *Borassus aethiopum* parklands develop on permanently cultivated village fields which are themselves subject to different intensities of land use. A decreasing gradient of *Borassus* tree density of 155, 127 and 87 trees/ha was found in three adjacent rings of village fields located at increasing distance from the village. Beyond these, bush fields are characterized by *Vitellaria* and *Parkia* parklands and the absence of *Borassus* (Cassou *et al.*, 1997).

Not only do parkland composition and structure result from the type and management intensity of agricultural activities, but they are also influenced by demographic changes. Reflecting such trends, Gallais (1967) outlined stages in the spatial expansion of *F. albida* parklands in the eastern part of the Kounari region in Mali. The continuum included villages with 'non-existent', 'limited' and 'extensive' parklands, as well as the separate case of 'distended' parklands. Villages in this region were devastated by wars and abandoned during the nineteenth century, after which access was open to exploitative wood cutters and herds. More recently, they have been recolonized. In places, trees were cut down and these lands may still remain treeless. In others, degraded parklands were regenerated, but where human density was low, the zone of so-called 'limited' parkland is now surrounded by a growing belt of permanently and extensively cultivated fields. Elsewhere in areas of higher population density and tight settlements, 'extensive' parklands ranging from the village houses through the cultivated zone were

Fig. 1.12 ***Faidherbia albida*** **parklands around Dolekaha, Côte d'Ivoire. Monospecific stands of** ***F. albida*** **are located almost exclusively in a belt around the village, while** ***Vitellaria paradoxa*** **and** ***Parkia biglobosa*** **parklands are located at a greater distance. Note sacred forest in lower right hand corner.**
D. Louppe

rapidly regenerated to support an intensively-managed farming system. Also, in agropastoral communities Gallais observed 'distended' parklands where an inner treeless zone used for cattle pens in the settlement area was surrounded by a parkland ring. The intensive use of *F. albida* branches for fencing pens and cattle pathways through the cultivated fields to outer grazing zones explained the low tree density in the village centre. Such a spatial pattern was also reported by Pullan (1974) in Birnin Kebbi in northwestern Nigeria.

Adjacent parkland areas with stands of trees of different sizes have often been reported (Pullan, 1974). One may find a central zone of cultivation with large scattered trees surrounded by an outer zone of smaller farm trees in far higher density, the latter being a zone of expansion of cultivation where conditions for natural regeneration are favourable. The condition of the woody cover on these newly cultivated areas depends on the intensity of wood collection, burning, and grazing. Gallais (1967) also noted variations in tree size ranging from 10-15 cm to 70-80 cm in diameter in the *F. albida* parkland stands of Mali which revealed their dynamic condition. These observations indicate a relationship between the size of parkland trees, which is often reported as relatively uniform within stands, and time of village occupancy or at least duration of cultivation. In southern Burkina Faso, average diameter at breast height of *Vitellaria* in farmers' fields was highly correlated with the number of years fields had been cultivated (Boffa, 1995).

The above parkland categories linked to soil management patterns or general land-use changes make up only one general component of the spatial analysis of parklands. Finer trends at various lower scales of analysis should also be pursued. Local situations generally hold a large diversity of different parkland types, which may overlap or contradict the proposed patterns (Depommier, pers. comm.). These locations may, however, yield significant information on a potentially wide range of variations in land use due to land saturation, land tenure modifications or economic

Box 1.2
Comparative tree growth in parkland and natural woodland conditions

Trees growing in parklands consistently stand out from those in the surrounding uncultivated savanna because of their size, in part due to the more favourable growing conditions. This has often been observed in *Vitellaria paradoxa* parklands in Mali and Cameroon (Ruyssen, 1957; Seignobos, 1982).

In tree savannas of the Sénoufo area in Côte d'Ivoire, tree density during first clearing was brought from a density of 1 000 trees per ha measuring from 5 to 60 cm in diameter down to about 100 stems per ha (Peltre-Wurtz, 1984). Most of the trees retained were *V. paradoxa* and *Parkia biglobosa*. The resulting reduction in competition for resources will eventually be reflected in tree size. In southern Burkina Faso, woodlands had an average density of 307 woody stems per ha with a basal area of 2.2 m^2/ha compared with 23 stems/ha with a basal area of 1.1 m^2/ha in fields (Boffa, 1995). Growth in the fields is thus concentrated on only a few selected trees which generally gives parkland stands a more mature appearance than uncultivated zones. In the same area, about 60 percent of *V. paradoxa* trees present in uncultivated quadrats belonged to the 0 to10 cm diameter range, whereas in cultivated fields 60 percent of trees measured between 10 and 25 cm in diameter. Likewise, on average, *Vitellaria* trees were about twice as large in diameter in cultivated fields (21.8 cm) as in uncultivated conditions (11.4 cm). The combination of limited grazing, fire, and wood cutting, as well as annual agricultural practices such as weeding, manuring or fertilizing, and reduced plant competition are responsible for this growth difference. Research has yet to establish the precise contribution of each of these factors.

constraints, etc., which are central to the dynamism of the systems. The age structure, density and composition of woody cover reflect compound management strategies at the ethnic, village, household, sub-household and individual levels in response to various external factors which are analysed in this report. In addition, parklands vary spatially in response to ecological constraints such as position in the toposequence and soil type. In order to capture the dynamics of parkland systems properly, researchers should be concerned with all of these levels. This has methodological implications. Firstly, characterization techniques need to cover all the different scales from the region, *terroir*, and parkland unit, down to the field, field section and even individual trees. Secondly, these agroforestry systems demand a strong multidisciplinary approach and wide collaboration between various sciences including morphogeology, soil science, agronomy, forestry, geography, history, socio-economics, animal science, remote sensing, Geographic Information System (GIS) technology and others.

Parklands as a reflection of agrosystems and ethnicity

Ethnic groups differ in their settlement and land-management patterns, even in comparable arable landscape units. Variations in social organization may be reflected in general land-use patterns including parkland management strategies at village and regional scales, as illustrated in examples from Burkina Faso (Box 1.3) and Senegal (Box 1.4).

Box 1.3

Ethnic distinctions in land-use patterns: the case of the Lobi, Bwa and Mossi in Burkina Faso

Savonnet (1979) analysed the influence of historical events such as wars and colonization, as well as natural processes like population growth and decreased land availability, on land-use patterns among three major societal types in Burkina Faso: the Lobi, Bwa and Mossi. In the segmented Lobi society, colonialism resulted in the breakdown of social units, which originally included single lineages. The division into smaller units was accompanied by a relatively less organized and adapted land-use system as well as less elaborate management practices. In contrast, households in communal Bwa society adopted a larger communal organization including two or three lineage segments. Community cohesion was reinforced with the formation of larger villages as protection against the threats of expansionist raids by Cheikhou Amadou and his Macina empire. Colonialism, by bringing political stability and, later, infrastructure, market and agricultural developments allowed households to be more autonomous economically. However, settlement and land-use patterns, as well as group cohesion were maintained and land-management practices showed that Bwa communities adapted successfully to new conditions. The permanently cultivated zone with *Faidherbia albida* parklands was significantly more extensive in Bwa than in Lobi areas.

In the case of the Mossi empire, a centralized and hierarchical socio-political structure provided security during several centuries. The permanent residence of populations widely spread in villages resulted in highly anthropogenic and densely inhabited landscapes including cultivated fields and fallows under a parkland tree strata of *F. albida*, *Vitellaria paradoxa* and *Parkia biglobosa*. The strong socio-political organization was respected and maintained by the colonial power. In the 1950s and 1960s, under demographic pressure, settlements were scattered in smaller units, but poor soils and relatively rudimentary cultural practices led to a greater farm mobility and migration as well as the discontinuation of *F. albida* parklands.

The structure and composition of parklands may reflect the way an ethnic group manages the vegetation in fields and fallows. The composition of dominant species indicates the general type of agricultural system while secondary parkland variables may be determined more by cultural and ethnic factors (Seignobos, 1982). This may explain why early explorers observed variations in parkland composition as they crossed West Africa (Kirk-Greene, 1962, cited in Pullan, 1974). For instance, Seignobos (1982) illustrated how *F. albida* and *V. paradoxa* parklands reflected two fundamentally different agrosystems and rural societies.

Faidherbia albida is the dominant species of the Sérer parklands in Senegal (Pélissier, 1966). The cultivated area is divided into at least two or three zones cropped and fallowed in rotation on a biennial or triennial basis. Elsewhere *F. albida* parklands are usually associated with permanent cultivation. During the cropping season, cattle are restricted to fallow areas and circulation to and from the outer zones of uncultivated forest is facilitated by live and dead fences around fields and along paths. At night, they are tethered and progressively moved in order to ensure

Box 1.4

Ethnic distinctions in land-use patterns: the case of the Sérer and Wolof in Senegal

Differences in natural resource management between the Wolof and Sérer ethnic groups can also be attributed to differences in social organization (Stomal-Weigel, 1988; Pélissier, 1966). Wolof society is characterized by a strong political structure, a conspicuous social hierarchy and commercial integration of their agriculture. Islam, used as a vehicle to gain political and economic power, has spread extensively. The Wolof rapidly responded to the introduction of peanuts as a cash crop. They favoured an extensive and cash crop-oriented land-use system, where new areas were cleared and extensively cultivated, food crops became gradually less prevalent and livestock production was emphasized.

In contrast, Sérer society is an apparently egalitarian one rooted in elaborate agricultural traditions and technologies. These included millet production and the integration of livestock and crop production (Stomal-Weigel, 1988) as well as the pervasive protection of *Faidherbia albida* trees in order to maintain high soil fertility levels and enhance millet grain quality and productivity. In the 1950s, peanuts were incorporated in the farming systems while Sérer agricultural traditions, including an intensive soil fertility management system and dominance of food crops, were maintained (Gastellu, 1981, cited in Seyler, 1993). These production systems sustained a significantly higher population density than the more extensive Wolof system.

A national agricultural modernization programme was implemented between the mid-1960s and the 1980s which emphasized green revolution techniques (improved varieties, fertilizers, animal traction) (Seyler, 1993). Overall, this resulted in a reduction of crop yields, crop diversity, and fallow use as well as increased mechanization. These profound changes affected both groups but were more pronounced in Wolof villages (Stomal-Weigel, 1988). In particular, the *F. albida* parkland system and other traditional cultural techniques persisted among the Sérer while they deteriorated in Wolof villages. The recent structural adjustment programme, including privatization, subsidy elimination and lifting of agricultural price controls, appears to have stimulated Wolof interest in using these techniques, as no differences were observed in *F. albida* crown cover, density or regeneration rates on Wolof and Sérer fields in the early 1990s (Seyler, 1993). Nevertheless, Seyler (1993) has shown that the Sérer could be distinguished from the Wolof by a higher parkland density of species other than *F. albida*, higher use of soil conservation measures (windbreaks, live fences, etc.) and a higher population density. Some of these factors may also be due to the more favourable climatic conditions in Sérer country.

homogeneous manuring of fields. After harvest, they are free to roam throughout the village, but remain secured at night.

Trees, cattle and crops are strongly interconnected in an intensively managed system. Trees contribute to the maintenance of soil fertility through nitrogen fixation and cycling of mineral elements from deep soil layers, but their pods and leaves also provide substantial quantities of fodder for cattle which, in turn, are a source of manure for soil productivity.

In contrast, *V. paradoxa* parklands may indicate an absence of cattle in the local farming system and little or no contact with pastoralists; *Vitellaria* kernels, from which a vegetable butter is extracted, compensate for the absence of milk and animal butter. This type of parkland is usually associated with a relatively stable settlement and a more extensive cropping regime than in the case of *F. albida*. Farmers typically clear and cultivate fields at the village periphery, beyond a limited zone of permanent cultivation around settlements, and these are shifted further out after three or four years of cultivation, while a fallow period of 12 to 15 years is applied. Land availability permitting, residence sites may be moved after two or three cycles to allow the land to rest longer. Over several decades, a stratum of selected trees, often dominated by *V. paradoxa* and *P. biglobosa,* develops. This land-management system requires a large area of land and population density associated with *V. paradoxa* parklands therefore tends to be lower than in *F. albida* parklands. Unlike *F. albida*, the *Vitellaria* system supports only one aspect of the economy rather than the whole agricultural system.

Some authors argue that ethnic specificities could result in the mutual exclusion of the two species. For instance, Pélissier (1980a) claimed that the *Vitellaria* genus is absent from communities which are either purely agropastoral or have maintained close relations with cattle raisers. This would explain why it is not found west of the Falémé river in Senegal. However, natural factors limiting the extension of the species could also be responsible. The presence of both species in the Dagomba area in Ghana as well as in other places in West Africa illustrates their compatibility (Sène, 1998). The two species are also interspersed where distinct ethnic groups used the same area either subsequently or simultaneously as a result of adoption (Marchal, 1980; Gallais, 1967; Savonnet, 1959; Dubourg, 1957). For example, in Dakola, Burkina Faso, stands of *F. albida* are found only in very old settlement sites established by Dogon and Samo populations before the Mossi conquest, which subsequently introduced *V. paradoxa*, *P. biglobosa* and *Tamarindus indica* (Kohler, 1971). This is also what Izard-Héritier and Izard (1959) and Marchal (1978) observed in Yatenga. Historical research in areas where the species occur together or exclude each other would provide highly interesting insights into the promotion of parkland species by various ethnic groups.

The influence of specific ethnic groups on the extension of parkland systems is also referred to by Pageard (1971). In Mali, the most elaborate and extensive *F. albida* parklands are located between Bamako and Mopti where sedentary cultivators of the Niger valley, namely the Bambara, the sedentary Peulh descendants of the Macina empire, and the Dogon people, live. In Burkina Faso, parklands and the emphasis on *F. albida* in myths and religious practices are mostly found among ethnic groups of the western provinces who were geographically closest to Malian groups associated with *F. albida* parklands. These parklands are rare in the Gourmanché villages of eastern Burkina Faso.

In northern Cameroon, from the Mandara mountains in the east to the Logone river in the west, *F. albida* parklands are most frequently encountered. However, *Prosopis africana* stands out as the most common species in some villages in the

Bec de Canard region (Bernard, 1996). Interestingly, these stands are circumscribed in a land pocket occupied by the Musey ethnic group, whose largest area of settlement is in Chad and surrounded by the more spatially dominating Massa populations. This group had a strong warrior and hunter tradition with a well established reputation. They are known for having fought the neighbouring Massa and Fulani and their strong cultural identity persists today. *Prosopis africana* was actively maintained in parklands because it provided stakes for decorating tombs and recalling the war or hunting feats of old Musey warriors. Whereas the surrounding Massa villages emphasize livestock production, the Musey raise Logone horses used in combat and hunting. However, cultural and technological changes have made the practice of regenerating *P. africana* less significant among young segments of the Musey.

Whereas the above-mentioned agricultural systems stand out because of the prominence of one or a few species, this is not always the case. In the Mafa region of Cameroon, where terraced agriculture is practised on the steep slopes of the northern Mandara mountains, parklands include several species, none of which is predominant. In this remote area farmers are relatively poor and self-sufficient. They maximize the use of trees, while minimizing their negative effect on crop production (Seignobos, 1982).

Summary

Parklands (or *'parcs arborés'* in French) are landscapes in which mature trees occur scattered in cultivated or recently fallowed fields. They are extremely variable, leading to continued discussion about appropriate terminology. They have been referred to as a vegetation type similar to 'tree savannas' but differ from these in that they are of specifically human origin, with the composition and density of their woody component manipulated in order to facilitate its use. Although occurring in other areas of the world, such as southern Africa and the Mediterranean, it is in the Sahel and Sudan zones of Africa that parklands are most widespread. No accurate figures exist at a regional level, but parklands constitute the predominant agroforestry system in semi-arid West Africa. They are most often characterized by the dominance of one or a few species. *Faidherbia albida* has received most attention in the literature because of its positive effect on soil fertility but it is likely that parklands dominated by *Vitellaria paradoxa* and *Parkia biglobosa* occupy the largest area.

Their origin in human agricultural activities meant that their study was generally neglected by early plant ecologists and the first in-depth system descriptions were undertaken by geographers in the 1960s. Several approaches have been used to distinguish types of parklands. First, they have been categorized according to the intensity of human management as residual, selected, constructed, proto-arboricultural or planted parklands. This perspective is useful in revealing the various degrees of management, but parklands characterized by a dominant species often do not fit exclusively into one or other of these categories. With increasing management intensity and dissemination of species and technology, the development of a mosaic of parkland types adapted to various niches may be expected.

Parklands have also been classified according to broad use categories. These systems have been established for the production of essential food complements, oils, wine, famine foods, wood, browse, crafts and for soil fertility restoration or a combination of these purposes.

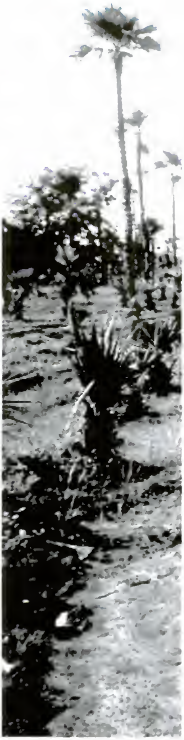
The age structure, composition, and density of parklands have also been analysed in terms of spatial variation. This corresponds in part to soil management practices, which decrease in intensity from compound fields through village fields to bush fields. Thus *Faidherbia albida* may be favoured on permanently cultivated village fields, while alternating fallow and cultivation cycles in bush fields may promote the development of floristically more diverse parklands with a *Vitellaria paradoxa* and *Parkia biglobosa* dominance. Tree size is correlated with the time during which fields have been cultivated. Thus, contrasts in size between parkland stands reveal land-use changes sometimes associated with demographic events. The growth rate of trees in parklands is generally higher than in uncultivated locations due to more favourable conditions.

Finally, the literature reports on the influence of ethnic identity and social organization on land-use patterns and parkland types. Examples in Senegal and Burkina Faso illustrate how land-use systems and agroforestry practices of several ethnic groups have evolved and become distinct through a number of processes including wars, colonization, population growth, decreased land availability and agricultural commoditization. Ethnic specificities have also been responsible for the promotion of given parkland species in some geographical zones. Fertilizer policies may also have a significant impact on traditional fertility maintenance and tree management practices. There are indications that removal of agricultural input subsidies in the late 1980s fostered *Faidherbia albida* regeneration in Western Senegal.

PARKLAND DYNAMICS

CHAPTER II

Parklands are extremely dynamic systems which may develop over many generations, reflecting changes in the physical and socio-economic environment. In spite of the importance of these systems, however, there is an almost complete lack of quantitative data in the literature concerning actual trends in parkland extent, density and age distribution over past years or decades. This chapter reports on various biological, cultural, socio-economic and policy conditions which have been conducive or detrimental to the maintenance and expansion of agroforestry parklands. Specific details on the biophysical factors affecting tree-crop interactions are provided in Chapter 3, while the impact of Sahelian forestry policies on parkland management is covered in Chapter 5.



Changes in tree density over time

In West Africa, the cultivated area has expanded as population has increased at an annual rate of 2.7 percent over the past decades. Frontier areas and river basins freed from onchocerciasis have been opened up for cultivation. In the Sahelian countries, agriculture has also expanded northwards, by about 150 km in Niger (Breman and Traoré, 1986, cited in Breman and Kessler, 1995). One might well assume that where the traditional practice of tree conservation in fields has been retained, the area of parklands should have increased.

While little is known about changes in parkland extent, it appears that tree density and regeneration in parklands have declined. For example, the annual rate of decrease in the density of large trees throughout the village of Petit Samba, Burkina Faso, was 0.15 trees/ha from 1957 to 1984 and 0.57 trees/ha from 1984 to 1988 (Gijsbers *et al.*, 1994). Whether density declined in its parklands was not specifically investigated; there was, however, a clear lack of small diameter classes. In Sob, Senegal, total parkland tree density decreased from 10.7 in 1965 to 8.3 trees/ha in 1985 (Lericollais, 1989). Decreasing tree cover in fields was also reported in Yatenga, Burkina Faso (Marchal, 1980). In contrast, an increase in density from 12.9 to 15.2 trees/ha and 6.1 to 6.7 trees/ha respectively, was documented in two large experimental sites of the Kano Close-Settled Zone of Nigeria between 1972 and 1981 (Cline-Cole *et al.*, 1990). Another study outside the Sahel and Sudan zones reveals that the volume of on-farm woody biomass in western Kenya has increased between 1986 and 1992 at an annual rate of 4.7 percent (Holmgren *et al.*, 1994). It did not specify, however, what percentage of the total woody volume was represented by scattered trees in fields.

A study by Fairhead and Leach (1996) in Kissidougou, a prefecture in the forest-savanna mosaic zone of Guinea, illustrates the importance of not jumping to conclusions about human impact on the landscape. In an area of 'derived savanna' in which forest islands were assumed to be relics of a more extensive forest long since degraded by local people, the comparison of aerial and satellite photographs taken in 1952 and 1992 showed that the area of forest and secondary forest thicket

Fig.2.1.'Construction' of a *Borassus flabellifer* parkland, Banfora, Burkina Faso
S.J. Ouédraogo

vegetation has remained remarkably stable and, in places, has expanded in surface area, sometimes considerably (50-500 percent). The study shows that many of the forest islands around villages were in fact established by local populations, and that the open savanna has also been enriched with more woody species. Even though it does not specifically deal with parklands, the study is useful in suggesting that scientists and policy-makers can misread decades of forest history and that methods used by farmers to enrich their landscapes can be obscured and marginalized. It also underlines the importance of historical research, using oral and documentary evidence, to understand vegetation changes in agroforestry parklands.

Data suggest that parklands have been degraded in term of tree density and that lack of regeneration threatens their sustainability.

It is difficult to draw clear and definite conclusions about general parkland trends, given the very small number of quantitative reports available. Caution is also needed in interpreting results as plot boundaries are not always described and overall numbers can conceal significant variations at the site, field or soil unit scale. Nevertheless, the literature is dominated by a general, qualitative agreement among researchers and practitioners that tree densities have declined significantly in Sahelian parklands and woodlands since the droughts of the 1970s. This assessment is very often consistent with villager perceptions. Given the long generation time for trees, the lack of young age classes in parklands should be a warning of a serious risk of degradation of these systems. However, as this report demonstrates, parklands are not uniformly in decline and show a great deal of resilience and potential for recovery and sustainability.

Even given favourable conditions, tree densities are likely to vary over time. As trees only have significant productive or environmental value after they have attained a certain size, parkland management takes place over several decades. The management period may include the practice of fallow for *Vitellaria* and *Parkia* parklands or protection of tree regeneration in the more permanently cultivated *F. albida* parklands. Often, tree density is related to the length of time an area has been farmed (Pullan, 1974) with density in newly cleared areas being higher than in old parklands (Otegbeye and Olukosi, 1993).

There are several reasons for this:

- Density management at the time of field establishment takes place during clearing and for several years afterwards. On a sample of oldest sections of fields cultivated for the first time in Thiougou, Burkina Faso, Boffa (1995) showed that field age as reported by farmers was the factor which explained the most variability in tree density. The annual rate of density decline was 1.1 trees/ha. The practice of continuing tree selection was not always reported, however. Because forestry agents have long imposed severe sanctions against tree cutting activities in Sahelian countries, farmer participation in parkland management may be underreported or maintained at below optimal levels.
- Annual labour availability for tree and bush cutting may be limited.
- Non-productive individuals are eliminated over the years. In Thiougou, farmers evaluated the potential productivity of *V. paradoxa* trees over a period of two to six years or based on immediate observation of tree condition, nut, leaf and bark characteristics (Boffa, 1995).
- Trees are also cleared to ease the passage of draught animals (Bagnoud *et al.*, 1995a; Boffa, 1995). In addition, tree sites are more fertile than surrounding areas for several years after tree death, as evidenced by better crop development. Farmers probably manage these sites actively in the context of micro-variability of soil fertility over the cultivation cycle.

- Finally, stands are thinned as trees grow larger and cover too much of the understorey cropping area. The difference between areas characterized by a large number of small trees and areas with a few trees with large crowns may be explained by differences in duration of occupancy (Pullan, 1974).

A decline in tree density over time may therefore be an inevitable process in the early part of the maturation of some parklands, such as *Vitellaria* parklands. The variety of objectives that farmers may be pursuing in establishing 'appropriate' parkland densities is also clear. Interwoven with the time dimension are environmental parameters which significantly affect tree growth and regeneration as well as parkland density, and which farmers integrate in their management decisions. Appropriate densities will be maintained in the long term only if farmers deliberately compensate for tree senescence and natural mortality with protected natural (or planted) tree regeneration. But farmers also manage the tree component of their farms in relation to other productive resources and in the context of various external influences, which make parkland management more complex. Additional factors responsible for changes in surface area, tree density and species composition in West African parklands are discussed below.

Natural factors

Drought

The effect of droughts in the 1970s and 1980s on tree survival and growth has been severe not only in natural woodlands but also in agroforestry parklands. Average annual rainfall during this period was at least 150 mm lower than during the pre-1970 period in seven village research sites in the Central Plateau and southwestern part of Burkina Faso (Lowenberg-Deboer *et al.*, 1994). This general

Box 2.1
Parkland regeneration in seasonally flooded areas

The Pondori zone of Mali, between Djenné (Mopti) and Tominian (Segou), is inhabited by Bozo fishermen, Marka rice growers, Bambara rainfed crop cultivators and Fulani livestock herders. Droughts have caused seasonally flooded areas suitable for rice production to shrink significantly since the 1970s. Likewise, available fodder resources have declined in *bourgoutières* (water-dependent communities of *Echinochloa stagnina* grass). These changes have aggravated resource conflicts between rainfed crop and rice farmers, on the one hand, and transhumant and sedentary pastoralists, on the other, and have induced diversification of local activities.

With the drop in flood water levels, there has been a significant advance of woody cover on previous rice production areas in the Pondori region. Dense *Acacia seyal* communities have developed on clay-rich vertisols. A combination of greater land availability and heavy pastoralist influence has resulted in a discontinuous scatter of *Faidherbia albida* (with densities of 50 to 200 trees/ha) encroaching on lighter soils in these formerly flooded zones. Bertrand and Berthe (1996) have extrapolated the future of these communities. Small mounds have progressively formed around *F. albida* trees and associated species through sand deposition, so that a moderate increase in flood levels will probably not result in their disappearance. It is likely that over the coming decades farmers will transform these tree communities into fully-fledged parklands for millet production as is practised in neighbouring zones. However, should floods reach pre-1970 levels, farmers would clear these areas and eagerly resume a much needed rice production (Bertrand and Berthe, 1996).

pattern is found throughout the Sahel and Sudan zones of Africa and has caused isohyets to shift south. The effect of drought on woody species has been more intense in the Sahel than in the Sudan, and on the upper parts of the landscape than in valleys (Breman and Kessler, 1995). Since the 1970s the occurrence of parkland tree species has declined in the northern part of their range. This is the case of *V. paradoxa* (Ohler, 1982, cited in Breman and Kessler, 1995). Ouédraogo and Alexandre (1996) also report that this species can now only be found in bottomlands in the Bam Province (600 mm rainfall) of Burkina Faso. However, drought does not always affect trees negatively, as illustrated in Box 2.1.

Livestock

Livestock is often assumed to play a determining role in breaking seed dormancy and increasing germination for parkland species such as *F. albida*. Researchers have therefore monitored the itinerary of seeds from fruit fall, which takes place during the dry season, from January to April in semi-arid West Africa, to seedling establishment. Contrary to popular belief, results suggest that livestock considerably reduces the number of viable seeds. In replicated stable experiments, only 2, 10 and 11 percent of healthy *F. albida* seeds ingested by sheep, goats and livestock respectively and found in faeces had retained their viability (Depommier, 1996b). Similarly, 84 percent of seeds consumed by enclosed sheep were digested in Ethiopia (Tanner *et al.*, 1990). A much higher percentage (65 percent) were recovered in ox faeces in Sudan (Radwanski and Wickens, 1967) but the experiment was not replicated.

After ejection in livestock faeces, some seeds will then germinate in the dry season and die shortly afterwards due to lack of rainfall or termite attack (Depommier, 1996b). The number of *F. albida* seeds available in faeces on farms in Watinoma, Burkina Faso, was only 500-1125 seeds/ha, and was higher under tree crowns where livestock seeks shade in the dry season than in open areas. The germination rate of seeds having undergone intestinal transit was only slightly lower (close to 80 percent) than either seeds treated with sulphuric acid and soaked in water for 24 hours, as normally recommended, or control seeds (both averaging over 90 percent). However, transit through animals resulted in significantly delayed and more gradual germination, which reached a maximum only after several weeks. The difference may be due to the fact that only seeds with the hardest tegument and thus the hardest-to-break dormancy resist chewing and digestion. Because the first rains are erratic and often followed by drought periods, this delay is a substantial advantage for survival.

Fig.2.2. Peulh herders let cattle browse pruned *Faidherbia albida* branches before piling and collecting the wood
R. Peltier

Therefore, rather than increasing or accelerating germination of *F. albida* seeds, livestock actually reduces potential germination. It does, however, contribute to wide dissemination throughout village fields (through manuring contracts with herders or spreading of manure collected in enclosures or compost pits), as well as enhancing seed

conservation and survival by delaying and extending germination. Livestock has a further negative impact on regeneration by trampling seedlings, and causing the partial or complete elimination of tree shoots. Its effects, along with drought and farmers deliberately cutting or destumping shoots during field operations in the rainy season, can result in very limited regeneration rates (Depommier, 1996a).

Pests

Drought, pests and exotic tree species have exerted pressure on parkland species.

Pests have also weakened some parkland tree populations. *Vitellaria paradoxa* trees are infected by parasites of the Loranthaceae family. Four species of *Tapinanthus* (*dodoneifolius*, *globiferus*, *ophiodes* and *pentagonia*) are widespread in Mali and Burkina Faso. Surveys indicate that up to 95 percent of *Vitellaria* trees may be infested in Burkina Faso (Boussim *et al.*, 1993a) and in Mali (Maiga, 1989). The effects of the parasites can include decreased wood quality, lowered resistance to pathogen attacks, decreased fruit production, and death of the tree. These parasites also affect other parkland species but to a lesser degree. In Watinoma and Dossi, Burkina Faso, 5-10 percent of *F. albida* trees were affected (Depommier, 1996a).

Potential sexual regeneration of parkland species through seeds can also be drastically altered through insect and bird attacks. In Burkina Faso, *F. albida* seeds are perforated by insects of the Bruchideae family, such as *Caryedon* sp. and *Bruchidius auratopubens* which feed on the seed embryo and cotyledons and destroy the seed's viability. Seed damage reached 75 percent on some *F. albida* trees in Watinoma (Depommier, 1996a), or comparable numbers in other studies cited by this author. A series of insects reviewed in Sallé *et al.* (1991) affect buds, leaves and reproductive organs, as well as branches and wood of *V. paradoxa*. The same situation probably applies to other parkland species. Likewise, birds such as *Lamprocolius* spp. removed seeds in 85-95 percent of *F. albida* pods from given trees (Depommier, 1996a).

Species composition and age structure in parklands are also evolving under the competitive influence of other tree species (Ganaba, 1996). Neem (*Azadirachta indica*) was introduced to West African Sahelian countries in the late 1910s through the English-speaking coastal countries. Since then, it has considerably expanded through planting for a variety of uses (primarily for shade, construction, medicinal and veterinary uses), and shows profuse and invasive levels of natural regeneration. This species grows better than others on rocky, lateritic and shallow soils and can withstand rainfall as low as 150 mm (von Maydell, 1983). It is disseminated by a variety of birds which induce faster germination by removing the fruit pulp.

Fig.2.3. *Azadirachta indica* invasion around *Faidherbia albida* trees in Dossi, Burkina Faso
S.J. Ouédraogo

Neem thrives in some parklands such as those of the Bulkiemdé Province, Burkina Faso. Farmers first planted it there on land unsuitable for crop production, then on areas close to compounds where densities of up to 4.4 trees/ha were recorded (Yélémou *et al.*, 1993). The progression of neem is also marked in village and bush fields in Watinoma, Burkina Faso

(Ouédraogo, 1994), and in Sob (550 ha), Senegal, where its numbers have increased from 3 in 1965 to 247 in 1985 (Lericollais, 1989). However, it competes aggressively with local parkland species for space and nutrients and dominates parkland regeneration. Dense concentrations of neem seedlings or suckers are commonly found around species such as *F. albida*, *V. paradoxa*, *P. biglobosa*, *Adansonia digitata* and *Ceiba pentandra* as a result of bird dissemination. The phenomenon is generalized throughout the Sahel and Sudan zones and appears to be detrimental to parkland species like *F. albida* (Depommier, 1996a). At the same time, in several places in West Africa, neem is reported to be declining, with signs of withering such as dead limbs, yellowing leaves, and a 'giraffe neck' appearance with only terminal leaves left on the tree. This condition is thought to be caused by a number of insects and fungal attacks. Neem decline is particularly severe in Niger where 30-40 percent of sampled trees are affected, and may be related to the narrow genetic base of the first introductions there (Direction Nationale de l'Environnement, 1998).

Economic and socio-cultural driving forces

Products from parkland trees are a significant economic resource. Farmer interest in maintaining and regenerating parklands therefore depends on the value of their products relative to other products of the land, or alternative income-generating activities.

In northern Côte d'Ivoire, management of *Vitellaria* tree densities responds rapidly to changes in the relative prices of its products (Louppe and Ouattara, 1996). When *Vitellaria* nuts or butter sell for high prices, regeneration is promoted. Conversely, if fuelwood prices outstrip those of the tree's other products, trees tend to be felled and sold on the fuelwood market. The increased commercial exploitation of fruits from parkland species can result in local-level regulatory action to maintain the production capacity of tree stands, as Wiersum and Slingerland (1997) observed for *Detarium microcarpum* forests in southern Burkina Faso. Similarly, Bergeret and Ribot (1990) noted that the proportion of useful and multipurpose tree species protected in fields increased between 1968 and 1987 in Kumbija, Senegal (though density data were not reported). Farmers appeared to respond to the decreased availability of desired species in village forests, due to droughts and the intrusion of tree cutters for charcoal making, by regenerating trees on lands they could still control.

In southern Niger, Mayahi *arrondissement* (Maradi department), where rainfall ranges from 200 mm in the north to 450 mm in the south, has experienced spectacular changes in the management of woody vegetation in fields over the past decades (Joet *et al.*, 1998). The low population density and relative

Fig. 2.4. Fruit of *Vitellaria paradoxa* ssp. *nilotica* held by a farmer participant of the Shea (Yao) project in Lira, northern Uganda
E. Masters

abundance of woody vegetation in range and fallow lands near villages led farmers to clear woody vegetation for cultivation and remove (construction and fuel) wood and fodder without planning for the renewal of resources which appeared unlimited. In the 1980s, as a result of drought and demographic increase, the disappearance of fallows and woodlands and the unavailability of wood on these collective lands prompted farmers to adopt regeneration practices in their own fields. Improved clearing techniques, in which the sexual or vegetative regrowth of woody plants in fields is protected, were introduced and extended in the region by several projects in the 1980s and have spread spontaneously to several dozen villages in Mayahi.

Farmers in the Ahmar mountains around Alemaya in eastern Ethiopia increase the area interplanted with *F. albida* because they need to obtain cash earnings and several products from the same land unit (Poschen, 1986). However, one of the major cash crops, *ch'at* (*Catha edulis*), is susceptible to leaf diseases under shade and its growth phases overlap too much with those of the trees. As landholding size tends to decline with increasing population density, Poschen (1986) fears that tree density in fields will decline as the need to intensify ch'at cultivation is felt.

In Wolokonto, Burkina Faso, *Borassus aethiopum* parklands, characterized by 90 percent of trees being in the early development stage, are expanding both spatially and in density due to the high income generated from palm wine (Cassou *et al.*, 1997). Significant tree regeneration and existing extraction skills currently ensure the sustainability of these parklands. However, Cassou and colleagues (1997) raise concerns about its future maintenance by younger generations attracted to higher urban salaries, plus the decline in wine demand resulting from the rising number of Muslim farmers. Likewise, Bernard *et al.* (1996) hypothesize that the local trade in *Vitellaria* and *Parkia* tree products partly accounts for the development of these parklands in northern Côte d'Ivoire, where densities have increased over the past three decades.

Noticeable increases in parkland density were also observed between 1972 and 1981 in the Kano Close-Settled Zone of Nigeria which has a close connection with the urban economy and population densities in excess of 200 people/km^2 (Cline-Cole *et al.*, 1990). The woody vegetation might have been expected to be severely stressed by an accentuated reliance on trees for fodder, food, and wood after the severe droughts in 1969-73. Instead, the large number of small diameter trees was evidence that farmers had been making a spontaneous effort to conserve, regenerate and plant trees in response to commercial opportunities for fuelwood and other products.

In some areas of Uganda, the *Vitellaria* tree is cut for charcoal-making in spite of its economic importance as a source of cooking oil (Masters and Puga, 1994). Where a strong cultural tradition of *Vitellaria* conservation exists, trees are maintained and used for butter production. The introduction of effective labour-saving technologies and the expansion or creation of markets to improve profitability have therefore been a priority for development projects focusing on the conservation and improved utilization of *Vitellaria* and other parkland species such as *Balanites aegyptiaca*, *Parkia biglobosa*, *Tamarindus indica*, *Azadirachta indica* and *Jatropha curcas*.

According to Hervouët, (1980, cited in Dallière, 1995) *F. albida* parklands were abandoned starting in the early 1900s among the Bissa, around 1940 among the Senoufo, around 1960 among the Bwaba and around 1970 among the Bissa and Samo in Burkina Faso in response to a conjunction of factors including the monetarization of the economy. Vimbamba (1995) argues that the cutting prohibition associated with species such as *Khaya senegalensis* led farmers in some areas to cut down and sell *F. albida* trees in order to pay taxes and make wooden utensils. This explanation may be debatable in view of the relatively poor

quality of *F. albida* wood (Depommier, 1996a), but it may be linked to the local unavailability of species providing higher wood quality.

Where traditional products from parkland trees can be substituted by cultivated crops or items purchased at the market, farmers may be less motivated to regenerate parklands. In Yatenga, Burkina Faso, Marchal (1983) noted that milk was becoming increasingly dominant as a fat source and substituting for oil from *Vitellaria* trees. Schreckenberg (1996) observed that the Anii and Logba groups in Benin prefer the taste of palm oil to that of *Vitellaria* when they can afford it. Across the border in Togo, both these oils are being replaced by groundnut oil (Sauvaget, 1981), which is less variable in inter-annual yield and less arduous to process. Likewise, Maggi cubes or fermented soybeans represent potential commercial substitutes for fermented *Parkia* seeds. Larger market organization may also sustain the development of parkland trees. The small size of local markets appears to constrain the rising mango production in Rakaye on the Central Plateau of Burkina Faso (Vimbamba, 1995).

The value of parkland tree products can also influence farmers' objectives in parkland management. Before the drought in Burkina Faso, exploitation and reduction of the environmental effect of trees were the primary motives for pruning *Parkia* trees. Nowadays, *Parkia* fruits have become more valuable due to the relative decrease in density of *Parkia* individuals over the period and their more extensive commercialization. Consequently, farmers manage *Parkia* trees as a significant resource in their own right and mostly carry out pruning to promote fruit production rather than to reduce the potentially negative impact of the canopy on crop yields (Timmer *et al.*, 1996).

Fig. 2.5. The COVOL (Cooperative Office for Voluntary Organizations of Uganda) hand press for extracting shea oil, Lira, Uganda
E. Masters

There have also been changes in the economic condition and socio-cultural traditions which sustained parklands. These are having an impact on management practices. Unlike the self-sufficiency prevailing several decades ago when parklands were developed or maintained, villages are no longer economically isolated. Important population movements have taken place during the 1970s and 1980s, including emigration from rural areas toward cities, coastal states and the southern parts of Sahelian countries. Villagers often rely on remittances from relatives living in these settlement zones. Younger generations are faced with the existence of opportunities in urban centres. In contrast, management of village lands in the past was self-contained and governed by strict traditional rules.

Some authors argue that the lessened villager interest in products and services offered by trees may be reflected in parkland degradation patterns observed in some places (Lericollais, 1989; Seignobos, 1996). However, one should also be concerned with how rural emigration affects demands for agroforestry products. Food habits regarding such products as *P. biglobosa* soumbala, *V. paradoxa* butter, *Bombax costatum* calyces, etc., are not necessarily altered as migrants come to live in urban areas. Links between village residents and urban migrants may then serve as a means of relating supply and demand and

provide a channel for informal or market exchange for these products. Although the widening of village economies and urban migration may appear to have a detrimental effect on resource management, they also open up new opportunities for the processing and marketing of parkland products due to increased market size and demand for more elaborately processed or packaged products, etc. (Ndoye *et al.*, 1997; FAO, 1995). These factors represent driving forces for the domestication of parkland species, as discussed in Chapter 4.

Prosopis africana parklands, as developed by the Musey of northern Cameroon, represent a somewhat unique system that was motivated primarily by socio-cultural factors rather than by agronomic and/or forest production benefits (Bernard, 1996). Social recognition among the Musey revolved around accomplishments in warfare and hunting. The horses they raised enhanced a warrior's social image and were prepared and venerated during rituals before combats. *Prosopis africana* was another indicator of social distinction. It was systematically protected by the group and was exclusively cut for funerals to decorate the tombs of respected clan members who were sometimes buried with their horses. Traditional taboos and ceremonies related to the way of cutting *Prosopis* trees upheld the tree conservation practice. However, the collective importance of these traditions has waned with the

Box 2.2

Processing and marketing incentives for the conservation and utilization of parkland trees: the case of Vitellaria in Uganda and Parkia in Senegal

Farmers are rational decision makers and will choose to conserve and regenerate trees in their fields or the wider farming environment if this brings higher benefits than destructive uses of the trees or alternative income-generating activities. Projects have therefore focused on increasing the overall profitability of maintaining parkland trees. The following examples illustrate how technology improvements, combined with the development of commercial outlets for parkland products which meet consumer expectations, may encourage a lasting involvement of local producers.

Traditional oil extraction from *Vitellaria paradoxa* kernels is a time and labour-consuming process. It also requires large amounts of water and fuelwood, and shows low production efficiency. The development and introduction of improved extraction technologies has, therefore, been one of the central objectives of the Cooperative Office for Voluntary Organizations of Uganda (COVOL) Shea Project in northern Uganda, where large populations of this species are threatened by cutting for charcoal. After a thorough study of existing presses in West Africa, the project designed, tested and further modified a press prototype. This has proved durable, reduces fuelwood consumption 20 times, and can process 25 kg of kernels per hour, which is about 10 times faster than the traditional method. It also results in higher quality oil. Presses have been bought and are now used by several rural women's groups in the area. Producers can also rent grinding facilities which further reduce the labour involved.

However, the added expenses incurred by local communities for improved extraction can only be justified if the improved productivity and quality of extraction also results in higher market rewards. With the objective of maximizing the economic profits for local producers, the Shea Project has therefore worked to develop a stable international export market with a natural cosmetics retailer in California who offers a high price to the Project for a high-quality packaged shea butter. This outlet gives women's groups double the local price for a jerrycan of shea oil. The project is also focusing on expanding domestic market opportunities, as shea oil is a popular traditional cooking oil. This includes an initiative to market shea oil in attractively packaged containers in major towns of northern Uganda as well as in Kampala, the capital city. This will reduce the potential risk of increased

disappearance of tribal warfare, the prohibition of hunting fires, and the transfer of farmer interest from ponies to oxen for animal traction. Younger generations tend to discount animist beliefs in favour of introduced religions. Farmers also report that schooling has diverted children from chasing crop-damaging birds away from crops. Control of bird damage is now achieved through tree removal. The ongoing degradation of *P. africana* parklands reflects the erosion of socio-cultural values which sustained this agricultural system until a few decades ago. The future of the species in Musey agroforestry systems will depend, among other factors, on the potential economic benefits (associated with its fodder properties and high timber quality) that can be derived from its integration with crops.

Another case of socio-cultural reproduction of parkland agroforestry practices is the development of *F. albida* parklands in Watinoma, Burkina Faso (Depommier, 1996a; Vimbamba, 1995). When he took up his position about 30 years ago, the current village headman, who originated from a nearby area with a strong *F. albida* tradition, started regenerating the species in his own fields. In the general context of land degradation, and exposure to R&D activities, he was imitated by villagers, who became convinced of the species' role in restoring the fertility of their soils, and revived the *F. albida* tradition.

production flooding local markets. As the domestic market develops, the project plans gradually to hand over post-harvest processing, packaging, marketing and distribution of shea products to the private sector (Kisakye *et al.*, 1997).

Conservation of some species may result from competition with substitute products. In West Africa, for example, fermented *Parkia biglobosa* seeds are widely consumed as a spicy seasoning for sauces complementing cereal dishes. It is called '*nététou*' in Senegal, '*soumbala*' in Burkina Faso and Mali, '*dawadawa*' in Ghana, and '*iru*' in Nigeria. Although deeply rooted in local food habits, *nététou* can be substituted by industrially processed stock cubes, such as '*Maggi*' cubes, which, with the help of intense advertising, have spread rapidly in Senegal especially in urban areas. A number of constraints in the processing technology, and product quality and presentation, appear to limit its capacity to compete and the further development of its market. A partnership between CIRAD-SAR (*Département des systèmes agroalimentaires et ruraux du Centre international en recherche agronomique pour le développement)* and CADEF (*Comité d'action pour le dévelopement de Fogny)*, a local development committee including 45 village groups of the Fogny area of Basse Casamance, in collaboration with ISRA (*Institut sénégalais de recherche agricole*), ENEA (*Ecole nationale d'économie appliquée*) and CIEPAC (*Centre international d'éducation permanente et d'aménagement concerté*) was established to tackle some of these constraints.

In the traditional processing of *nététou*, seeds are boiled for 12-24 hours, then dehulled by pounding with sand, and thoroughly cleaned in order to eliminate residues. Dehulling and cleaning of 25 kg of seeds can take up to 3 hours. In a second stage, seeds are boiled, drained and fermented for 2-3 days. After testing several prototypes, a machine for dehulling and cleaning seeds was designed locally. This has eliminated the first processing stage and increased processing capacities to 70-80 kg/hour, while also dramatically reducing fuelwood consumption. In order to give women producer groups increased bargaining power, the project has also undertaken a study of the commercial sector of *nététou* in Senegal. Direct marketing arrangements have been put into place between producer groups in Fogny and organised retailers in Dakar originating from the same area, and links established with other rural organisations in the area. In addition, the project has developed several new *nététou* products in order to overcome the concern of Dakar housewives that traditional *nététou* is prepared and commercialized in unhygienic conditions. The marketing of *nététou* paste, powder and cubes in sealed, clear plastic bags appears to hold promise for reviving consumption of this traditional food item (Ferre, 1993).

Agricultural development policies

In past decades, a number of developments aimed at increasing farm productivity have had important indirect effects on parklands. This section illustrates how the conception of the general role of trees in agricultural development models, technological developments such as animal traction, the intensified production of cash crops and use of inputs, cultural innovations and fertilizer subsidies have influenced the condition of parklands.

Role of trees in agricultural development models

Extension services have only recently advised farmers to integrate trees into agricultural systems. In the 1950s and 1960s, agricultural development models in West Africa promoted geometrically shaped fields devoid of woody cover where single cropping was prescribed. Trees, especially of local origin, were ignored or even considered as obstacles to the development of intensive and productive systems. In places, financial credit for agriculture was given only if all trees were cleared from fields. Trees had little role to play in land improvement schemes and were thought to be incompatible with animal traction or more intensive mechanization. Such models pervaded strategies of research, extension and development as well as commodity parastatal agencies during this period. References to these early land management projects by agricultural agencies are given for Senegal (Lericollais, 1989) and Cameroon (Seignobos, 1996). This trend was also evident in Zambia and Zimbabwe until 1980 or so (Campbell *et al.*, 1991). Insufficient consultation among natural resource disciplines including agronomy, soil science and forestry probably hampered the integration of trees in the agricultural agenda. Awareness of the insufficiencies of these early development projects gradually led to more consideration of the role of trees in sustainable agricultural systems, and natural tree regeneration was included in some projects (Montagne, 1984; Taylor and Rands, 1991). Only more recently, however, have agricultural extension and development agencies begun to support the maintenance and regeneration of trees in fields (Joet *et al.*, 1998).

Fig. 2.6 Oxen traction for sowing cotton in *Parkia biglobosa* parklands, Dolekaha, Côte d'Ivoire
C. Bernard

Mechanization

Farmers using animal traction generally maintain a lower tree density in their fields, but this varies according to location and production objectives. Trees are eliminated to give draft animals space to manoeuvre and to reduce ploughing or ridging problems where tree roots are superficial. Traditional cultural practices were substantially altered under direct outside influence in Gallais' example in Mali (1967). Bergeret and Ribot (1990) also report from Senegal that government subsidies encouraged

farmers to clear their fields of all trees and stumps when animal traction was introduced. A similar process of tree removal was reported in central Gambia (Weil, 1970, in Freudenberger *et al.*, 1997). In three cotton-producing villages of southern Mali, densities of trees in fields were almost twice as high (about 16 to 23 trees/ha) on farms where mechanization was absent or incomplete as in those well equipped with animal traction (about 8 to 13 trees/ha) (Bagnoud *et al.*, 1995a).

Fig. 2.7. Mechanized cultivation in *Vitellaria paradoxa* parklands, Bole, Ghana. Note lack of woody regeneration.
P. Lovett

In northern Côte d'Ivoire, soil cultivation by tractors led to the drastic elimination of trees in the early years after the introduction of cotton (Bernard *et al.*, 1996). As farmers later abandoned the use of tractors and adopted less expensive animal traction, they encouraged tree regeneration. Currently, tree density is slightly higher in farms with animal traction (15 trees/ha) than among hand-cultivating farmers (12 trees/ha) but not significantly so. In the *Vitellaria* parklands of Thiougou, a frontier village in southern Burkina Faso, farmers using hand cultivation, donkey and ox traction had tree densities of 31, 25 and 21 trees/ha respectively (Boffa, 1995). The difference was statistically significant between farmers using manual labour and those using oxen. The relatively high density of trees in Thiougou, even in fields cultivated with oxen, may be related to the recent conversion of lands to agriculture and the limited size of parkland trees, as well as the fact that production is almost exclusively oriented towards staple rather than cash crop production. The lighter plough and greater manoeuvrability of single animals in donkey traction had less of a depressive effect on parkland tree density. These examples show that, depending on the degree of agricultural intensification, trees need not be incompatible with animal traction.

The extent to which animal traction is hampered by trees depends on the rooting patterns of parkland species. *Faidherbia albida* is generally not considered a significant obstacle in the northern part of the Sudan and Sahel zones, because of its deep tap rooting habit, yet under higher rainfall conditions superficial rooting can be a constraint to mechanization (Bernard *et al.*, 1996). Animal traction can also promote tree regeneration. In the shallow or hydromorphous soils of Watinoma and Dossi, Burkina Faso, regeneration of *F. albida* suckers was common on superficial roots where they had been partly or completely cut by a plough (or hoe) (Depommier, 1996a). This type of vegetative reproduction was believed to form a significant part of local *Faidherbia albida* parkland regeneration.

Crop introduction and development

Intensive cash crop production supported by the use of chemical fertilizers has led to parkland degradation in several places. In Mali, between the Niger and Bani rivers, the intensification of cotton production had a detrimental impact on parklands (Gallais, 1967). Following its introduction during World War II, cotton was associated with staple crops in bush fields. In the early 1950s, the French

parastatal textile company, *Compagnie française de développement des textiles* (CFDT) successfully promoted mechanized cotton production in compound fields. As a result, farmers reduced the *F. albida* cover in these fields and cereal crops were transferred to bush fields. These conditions probably made production more vulnerable to drought and soil productivity less sustainable (Gallais, 1967). Farmers had also cleared all tree cover including *F. albida* in dry-season onion plots in bottomlands.

The decline of field tree density to the current level of 5 trees/ha in the M'borine area of Senegal is partly attributed to the introduction of groundnuts as a short fallow cash crop, as well as the decline of indigenous fallowing methods (Postma, 1990, in Shepherd, 1992). Tree density was more intensely reduced in cotton fields located in valleys than in other valley fields in Petit Samba, Burkina Faso (Gijsbers *et al.*, 1994). In western Burkina Faso, intensive cropping systems under *F. albida* cover, which allowed high population densities on limited cultivated zones, have been neglected with the development of extensive cotton production in bush fields. Such a process has been felt in the last 20 to 25 years in the village of Dossi (Depommier, 1996a). In the Central African Republic, clearance of *V. paradoxa* and *P. biglobosa* trees in cotton fields was supported by SOCADA, the national agricultural development agency which focused on improvement of cotton production (Depommier and Fernandes, 1985).

In the village of Holom in the Bec de Canard area of northern Cameroon, *Prosopis africana* parklands, a rare form of parklands in Africa, have deteriorated, as indicated by a 50 percent overall tree mortality rate and a virtual absence of *Prosopis* regeneration in fields. Cotton introduction is held responsible for this decline (Bernard, 1996). The displacement of traditional staple crops resulted in a reduced practice of fallowing (in time and land area), which previously allowed for tree regeneration. In the soil management schemes promoted by SODECOTON, the company that superseded CFDT, the fertility enhancement function of fallows was replaced by the use of chemical fertilizers. In addition, trees are generally systematically excluded from plots in SODECOTON's technical package, whether directly or through the impact of animal traction.

Furthermore, plot layout and management patterns applied by the cotton agency do not conform to traditional land division and tenure arrangements. Thus the drastic expansion of cotton production (58 percent increase in area in two years) has been accompanied by an increase in land loans. Cotton is grown in blocks of land which may not correspond to former field boundaries and which are relocated on an annual basis, resulting in complex tenure situations. The alteration of land tenure rights also causes a modification of tree management strategies. For instance, the highest density of dead or dying *P. africana* trees in Holom-Nguéring is found on plots loaned for cotton production to farmers of neighbouring *quartiers* (quarter) and villages. Some of these borrowers argue that they are descendants of the founder of the first settlement of Holom and claim primary landholding rights over cotton plots. Bernard (1996) hypothesizes that the gradual elimination of trees may be a way of removing existing signs of traditional tenure and gaining exclusive land rights for the production of this cash crop.

Finally, in order to compensate for the reduction of the area previously cultivated with staple crops, farmers adopted *muskuwaari*, a dry-season sorghum variety. This is planted in periodically flooded depressions with clay soils, and on the whole its labour input does not overlap with that of cotton production. But farmers systematically clear all trees on and around bottomlands where *muskuwaari* is grown, to control bird depredation. The substantial displacement of rainfed crops

by cotton and the transfer of cereals into bottomlands have thus been detrimental to the maintenance and expansion of *P. africana* parklands in this area.

However, the negative impact of modern technologies on parklands may relate to the way they have been applied rather than their incompatibility. Other evidence exists to show that technological change can have positive effects on parklands. In northern Côte d'Ivoire, *Parkia* and *Vitellaria* parklands around the village of Dolekaha showed a significant increase in tree density while cultivation area remained stationary between 1962 and 1993 (Bernard *et al.*, 1996). And this parkland development took place during the booming growth of cotton and maize production stimulated in part by input availability. Bernard and colleagues postulate that cash crop production and the associated use of chemical fertilizers have extended the cultivation period, thus contributing to the growth of these parkland trees, which was previously constrained by the short (two or three year) cropping cycles. The growing trade in *Parkia* and *Vitellaria* products also favoured their protection.

The area of *F. albida* parklands is expanding in northern Cameroon, where tree density is increasing in existing parklands, trees are regenerating in relic parkland areas, and new parklands are appearing at the southern edge of the Mandara mountains (Seignobos, 1982). *Faidherbia albida* progresses in a northwest direction from the Tupuri area toward the Diamaré region. This is partly due to the development of a *muskuwaari* sorghum variety which can be transplanted from inundated bottomlands to uplands where *F. albida* parklands are developing. It is also thriving north of Massa country among Bege populations.

In Musey society in southwestern Chad, there is currently a shift from horse breeding to a system of livestock raising and cropping. Villages are becoming more sedentary and these changes are reflected in an increase of *F. albida* parklands (Seignobos, 1982). Significant *F. albida* regeneration is also reported south of Zinder, Niger, in areas which were extensively cleared for groundnut production during colonial and early postcolonial times (Taylor and Rands, 1991).

Fertilizer policies

Agricultural policies in the late 1960s and 1970s which emphasized the use of green revolution technologies, including improved varieties and mineral fertilizers, also had a significant impact on tree management practices in some areas. The economy of Senegal's North Central Peanut Basin has relied on peanut production since its introduction in colonial times. Until the early 1980s, emphasis was placed on state intervention through input and credit provision, setting of commodity prices and control of industry and agricultural development agencies. Seyler (1993) found that the impact of fertilizers tended to substitute for the fertility effect of *F. albida* where it occurs. Low fertilizer prices and a state-protected agricultural sector inadvertently discouraged farmers' continued investment in *F. albida* regeneration in western Senegal (Seyler, 1993).

The analysis of United States Agency for International Development (USAID) data from 1965 to 1989 revealed a significant relationship between fertilizer subsidy and area cultivated in peanuts in the *Départements* of Thiès and Diourbel. Both increased between the mid-1960s and the late 1970s and then stabilized in the early 1980s in the transitional period when the first structural adjustment loan was approved but reforms were not fully implemented. Finally both variables decreased significantly with the implementation of the structural adjustment programme in the second half of the 1980s which focused on state

disengagement, commodity diversification, and privatization. Questionnaire data collected in the same region suggested that the area cultivated in peanuts declined between 1985 and 1989 while the area under cereals and cowpeas increased, and the use of manure and *F. albida* regeneration in fields increased significantly (Seyler, 1993).

Agricultural development policies have also had a drastic impact on parkland systems...

Based on retrospective estimates of tree age from diameter measurements, *F. albida* densities were shown to be inversely related to the amount of fertilizer subsidy. In a first stage, farmers favoured the use of cheap fertilizer for maintaining soil fertility rather than emphasizing the conservation of *F. albida* cover in their fields. As fertilizer subsidies were reduced or eliminated with the new agricultural policy in the mid-1980s, they resorted to traditional methods of fertility conservation such as manuring and protection of *F. albida* trees. Furthermore, farmers reported that the close row spacing in peanut cropping makes intercropping with *F. albida* impractical and that, unlike the hand harvesting of millet and sorghum, the mechanical harvesting of peanuts also results in the loss of *F. albida* seedlings. Therefore the decrease of peanut cultivation area associated with structural adjustment has had a positive impact on *F. albida* parkland densities (Seyler, 1993). Farmers also seemed to respond to the high input cost and resulting decrease in peanut income by protecting and increasing the fruit production of other on-farm tree resources. For instance, *Ziziphus mauritiana* fruits are sold in local markets as well as in Thiès and Dakar, and fruits of *Balanites aegyptiaca* are sold to oil pressers in the area (Seyler, 1993).

... for example by encouraging the clearance of trees to facilitate animal traction.

The above results were confirmed by a financial analysis of technological interventions for the region, including various scenarios of intensified (high input) agriculture or *F. albida* parkland technology. Analyses revealed that the net present value of the introduction/maintenance of *F. albida* was 40 percent higher than the fertilizer/high input model. Therefore, when fertilizer is inexpensive or highly subsidized, it makes more financial sense for farmers to spread low-cost fertilizer in their fields than to maintain *F. albida* populations. In contrast, farmers rely on *F. albida* parkland or other traditional soil conservation technologies when fertilizer is accessible only at market prices. General agricultural and economic policy had more influence on the conservation and improvement of the agroforestry parkland system in Senegal's North Central Peanut Basin than policies and projects focusing on the system itself (Seyler, 1993). It is also recognized that in Zambia and other southern African countries the removal of government subsidies on inorganic fertilizers led to the need for *Sesbania sesban*-based improved fallows (ICRAF, 1995a). Consequently, macroeconomic policies, including those concerned with agricultural input pricing, need to be carefully designed in order to ensure sustainable agricultural production and the maintenance and improvement of the natural resource base.

The analysis of *F. albida* parkland dynamics in this and the previous section does not, however, imply that mineral fertilizers and *F. albida* have similar functions and are mutually exclusive, and that the development of the one will lead to the decline of the other. The organic carbon and nitrogen inputs of *F. albida* can be considered complementary to the mineral inputs of NPK fertilizers. Furthermore, the species is found not only in nutrient-deficient soils, but is also maintained in fertile sites throughout the Sahel (Depommier, 1996a).

Can the results of Senegalese *F. albida* parklands be extrapolated to other areas and other parkland systems? That such policy changes could have a positive effect in other systems such as cotton cultivation in *Vitellaria* and *Parkia* parklands, is less obvious. The *F. albida* parkland system in western Senegal has several peculiar characteristics. The tradition for maintaining these parklands is deeply

rooted. (However, the departure from subsidized fertilizers also had a positive effect on Wolof farms whose agroforestry tradition may be less deeply rooted.) Secondly, the enriched soil fertility and improved crop production which could be expected from parkland species other than *F. albida* may not compare with those observed in the almost monospecific stands of *F. albida* in Senegal. Nevertheless, policies may similarly promote soil conservation or fertilization practices as a complement to agroforestry technologies. To the extent that appropriate agricultural policies may activate parkland agroforestry practices the question remains of interest, and the particular conditions warranting such changes are worth studying in detail throughout the zone of parkland occurrence.

Demographic relations

By shortening or eliminating fallows, increasing population pressure threatens the sustainability of* Vitellaria paradoxa *and* Parkia biglobosa *parklands.

There appears to be a clear association between population density and particular agroforestry parkland types. This section analyses this for the two most studied types: *F. albida* parklands, on the one hand, and *V. paradoxa* and *P. biglobosa* parklands, on the other. While this may clarify the peculiarities of each system, one should nevertheless bear in mind that given villages or regions often display a combination of both types.

There are many indications that *F. albida* parklands are able to sustain high population densities. Hallaire (1976) referred to systems including permanently cultivated fields under *F. albida* cover on terraces of the Mandara mountains in northeastern Nigeria and northwestern Cameroon and stall-fed cattle, with population densities as high as 300 inhabitants per square km. Recent population increase and development of rainfed agriculture around the Mandara mountains resulted in greater conservation and improvement of parklands which were previously abandoned during conquest by Fulbe herders (Seignobos, 1982). In the Hararghe Highlands of Ethiopia, *F. albida* parklands are common, due to a combination of high human population density, scant availability of uncultivated land and restriction of free grazing. However, these parklands are almost non-existent in the neighbouring Chercher highlands where different conditions occur (Poschen, 1986).

Likewise, in the Jebel Marra massif in Sudan, the degradation of the intensive *F. albida* system practised by the Fur was primarily attributed to a decline of population density over past decades (Miehe, 1986). Older villagers in the Koronga area reported that, 50 years ago, the population density was higher and the area cultivated permanently for more than 20 years was larger, while tree density in fields remained high and species composition constant. Currently, one may observe a relative scarcity of old trees on farmland and a lack of tree regeneration. This process is aggravated by a combination of socio-economic factors and by droughts. Traditional values, customs, and diets as well as the authority of local chiefs have eroded with monetization of the economy, commercialization and wage labour. With political security, part of the population leave the montane areas where the intensive *F. albida* parkland system is practised and move towards the plains to seek wage labour (Miehe, 1986). As pressure on land decreases, the remaining farmers adopt more extensive bush fallow or shifting cultivation.

Pélissier (1980a) also highlighted the fact that the Sérer in Senegal (700 mm rainfall) and the Brame and Mandjak in Guinea Bissau (1 500 mm rainfall) established a *F. albida* parkland system in order to support their high population densities of 50-100 and 100-150 inhabitants/km^2 respectively. In contrast, the Balant group, a similar sedentary agropastoral society located between the above-mentioned regions in

Casamance, Senegal, did not develop *F. albida* parklands. And the Massa Goumay group, while having created *F. albida* parklands around Koumi on the Logone river, did not reproduce them after migrating to the Chari banks where population density was three times lower (Seignobos, 1982). In 36 villages in the administrative districts of Thiès, Diourbel, Fatick and Kaolack in Senegal's Peanut Basin, Seyler (1993) found a positive relationship between population pressure ranging between 50 and 100 inhabitants per square kilometre and *F. albida* crown cover, regeneration rates, and seedling survival in agricultural fields. In Niger, Lemaître (1954, cited in Felker, 1978) observed several cases where well-stocked *F. albida* parklands were associated with higher population densities (25-40 people/km^2) than areas with no or little *F. albida* farm component (10-20 people/km^2). In these cases, farmers appear to increase their investment in labour and soil fertility enhancement activities with rising population pressure.

In specific conditions, an increase in population density appears to have opposite effects in* Faidherbia albida *and* Vitellaria-Parkia *parklands.

Faidherbia albida parklands are suited to permanent cultivation. The alternation of short cultivation and fallow intervals is detrimental to them. In fallows, field borders or grass strips, *F. albida*'s development suffers from competition from perennial grass species during the late part of the growing season, and fire. It is often absent in uncultivated zones of savanna, even those bordering fields (Peltier, 1988, cited in Bernard *et al.*, 1996; Harmand *et al.*, 1996). According to farmers, promoting the development of large *F. albida* trees in parklands is also a way of controlling its invasive development. Livestock grazing, the cutting back of *F. albida* shoots during field preparation, as well as ploughing operations cause persistent heavy resprouting and suckering (Bernard *et al.*, 1996; Depommier, 1996a; Seignobos, 1996). Large trees appear to limit the number of seedlings and suckers and are preferred to control this undesired regeneration. And being adapted to permanent cultivation, *F. albida* parklands can support relatively high human population levels.

In contrast, *Vitellaria* and associated *Parkia* parklands rely on alternating fallow and cultivation periods. Naturally, this implies that the number of people they can sustain per unit area is relatively low. Fallow phases allow for seedling establishment and early growth as well as soil fertility restoration, while subsequent selection and land cultivation result in relatively good growth due to protection from fire and perennial grass competition. The traditional sequence of cultivation and fallow periods as it took place before colonization was reconstituted in southern Chad (Gilg, 1970). Villages would adopt a 4-year cropping cycle followed by a 12-15 year fallow, which was repeated two or three times before the population would move to nearby sites to allow for restoration of soil fertility. Gilg (1970) also indicated that villages would return to sites cultivated in the past. The persistence of *V. paradoxa* in burned fallows is also partly due to its resilience to fire (Hopkins, 1963) and its fire-adapted germination patterns (Jackson, 1974).

In turn, increasing population, concurrent decrease in available arable land, and higher cropping intensity shorten or eliminate fallow periods, thus threatening the sustainability of *V. paradoxa* and *P. biglobosa* parklands. For instance, bush fields in Guetela and N'Tossoni in southern Mali have been cultivated permanently for the last 10 to 30 years and 10 to 15 years, respectively. This is in contrast to the traditional rotation of five years of cropping and seven to ten years of fallow which is still observed in Pourou, a village with less intensive agriculture (Bagnoud *et al.*, 1995a). While permanent (intensive) cultivation contributes to the maintenance of existing trees, it impedes tree regeneration. Thus small diameter (10 and 20 cm) size classes represented 32 and 30 percent, 8 and 7 percent, and 13 and 0 percent of all trees in Pourou, N'Tossoni and Guetela, for *Vitellaria* and *Parkia* species, respectively. For the same reason, overall *Vitellaria* and *Parkia* tree densities are usually lower in compound than in bush fields. Small diameter classes, however, may be more common in bush fields, which are usually fallowed, than in

permanently cropped compound or village fields (Dallière, 1995; Mahamane, 1996; Ouédraogo and Devineau, 1997). *Vitellaria* acquires a suckering ability after about four years of sufficient root and stem growth (Ouédraogo, 1994), and cultivation before this stage destroys it. While traditionally there is a contrast in tree density between compound and bush fields, the acquisition of carts tends to extend agricultural intensification to bush fields as well (Bagnoud *et al.*, 1995a). The presence of large trees is related to permanent site occupancy and long cultivation and fallow periods. However, old *Vitellaria* individuals seem not to be present in very old fallows. Nandnaba (1986) ascribed this phenomenon, observed in Nazinga, Burkina Faso, to their poor resistance to competition. In the light of Nandnaba's results, the traditional practice of long-term (up to 150 to 200 years) fallow resulting from long-term shifts in village location suggested by Gilg (1970) would imply that *Vitellaria* trees would no longer be dominant at this stage but would be part of a mixed woodland.

While the above paragraphs have contrasted the capacity of two parkland types to sustain population density, it should not be concluded that high population pressure necessarily leads to the degradation of parklands relying on farm-fallow cycles. The established conviction in many government forest policy bodies that population settlement and land use result in forest degradation is, increasingly, being disproved. In Kissidougou, Guinea, forest island density in 45 districts was positively correlated with population density (Fairhead and Leach, 1996). Similarly, there was a positive correlation between population density and the volume of planted woody biomass on farm at the district level in Kenya (Holmgren *et al.*, 1994). Within reasonable limits, farmers' response to rapid population growth can therefore lead to more intensive sustainable land management practices.

Summary

The spread of parklands has probably increased in line with the expansion of the cultivated area throughout the Sahel and Sudan zones of West Africa in the last decades. At the same time, a combination of qualitative and quantitative data suggests that parklands have been degraded in terms of tree density and that a lack of regeneration threatens their sustainability. However, decline of parkland cover is not uniform and these systems display a high degree of resilience. There is a deplorable lack of the comparative density and age composition data at distinct time intervals necessary to assess their dynamic condition. A decline in tree density is sometimes inherent in farmer strategies for long-term parkland development to reach appropriate tree-crop combinations and high fruit production, and does not necessarily imply degradation.

Parkland systems respond dynamically to a variety of natural, economic, socio-cultural, technical, demographic and political parameters. Factors including drought, pests and exotic tree species have exerted pressure on parkland species, whereas livestock contributes to seed dissemination and survival. When farmers perceive that trees and their products become valuable due to increased economic worth, greater demand or declining availability, they actively invest in the protection and reproduction of parklands. They also support stronger institutional arrangements and maintain the necessary knowledge base for the management of these systems.

In contrast, farmers tend to neglect their forest resources and favour alternative agricultural practices, items of consumption and income-earning activities when these yield higher benefits in terms of lower cost, higher revenue, lower labour expenditure, higher subsistence priority, better taste, etc., than those from surrounding parkland trees. External parameters such as markets, external pressure on village resources, migration and relations with urban centres strongly influence the relative value of parkland trees. In recent decades, socio-cultural motives, which have been a strong factor for the perpetuation of parkland agroforestry practices, have tended to lose ground against the monetization of the economy and associated technological change, leading to parkland recession.

Agricultural development policies have also had a drastic impact on parkland systems. Until recently, research, development, extension and commodity parastatal agencies encouraged the clearance of trees to facilitate animal traction. Superficial tree roots can impede the progress of ploughs, and most of the data available point to lower tree densities on farms equipped with animal traction than among manual cultivators. However, animal traction is far from incompatible with parkland agroforestry, as demonstrated by some fairly high parkland densities reported in Burkina Faso and Côte d'Ivoire. Cash crops, such as cotton, groundnuts and maize, were also introduced with the recommendation to clear parkland trees. They tend to displace traditional staple crops and replace fallow practices, which are responsible for tree regeneration, with the use of fertilizers. Alternatively, the use of fertilizers sometimes allows for longer cultivation periods between fallow cycles during which parkland trees can thrive. Cash cropping may encourage more exclusive control of fields and exacerbate tenure conflicts where land is used or claimed by multiple actors. When the historical basis of land access is in question, the conservation of trees, interpreted as a sign of past occupancy, may be jeopardized. Fertilizer policies may also have a significant impact on traditional fertility maintenance and tree management practices. There are indications that removal of agricultural input subsidies in the late 1980s fostered *F. albida* regeneration in Western Senegal.

An increase in population density appears to have opposite effects in *Faidherbia albida*, and *Vitellaria-Parkia* parklands. The *Faidherbia* system thrives with permanent cultivation, a virtual absence of fallows, and the intensive cropping practices resulting from high population numbers on a limited land area. As the need for intensive land use disappears with released pressure on land, the *Faidherbia albida* parkland system tends to dwindle. In contrast, the *Vitellaria-Parkia* parkland type depends on the alternation of fallow periods, which permit soil fertility restoration and tree regeneration, with cultivation intervals favouring the growth of selected trees. By shortening or eliminating fallows, increasing population pressure threatens the sustainability of *Vitellaria paradoxa* and *Parkia biglobosa* parklands.

BIOPHYSICAL FACTORS IN PARKLAND MANAGEMENT

CHAPTER III

Biophysical interactions between trees and crops have shaped the physical configuration of parkland agroforestry and are one of the primary determinants of the way farmers manage trees in their fields. This chapter examines the available qualitative and quantitative information on biological processes governing the biophysical influence of parkland trees on soils and crops. While the focus is on cultivated plants in parklands, reference is also made to the interaction of savanna trees and wild herbaceous species so that similarities and contrasts with parklands can provide a better understanding of the biophysical dynamics involved.

Tree-soil relations

The potential contribution of trees to soil improvement is one of the major assets of agroforestry in general and, more specifically, of agroforestry parklands.

Influence on soil chemistry

The enhancement of soil fertility by trees is conspicuous in studies which compare productivity of crops grown on soils formed under tree canopies and on control soils in open sites. For instance, Verinumbe (1987) found that maize and sorghum produced higher dry matter on soils collected in tree plantations than on ordinary field soil. Highest crop yields were obtained on soils from under *Azadirachta indica*, followed by *Prosopis juliflora* and *Eucalyptus camaldulensis*. Total biomass of millet plants grown on soils sampled under *Hyphaene thebaica* and *Faidherbia albida* in Niger was 63 percent higher than of those grown on soils sampled away from trees (Moussa, 1997). In Senegal, similar trends were reported for millet and groundnut under *Cordyla pinnata* and in the open (Samba, 1997). In parklands, one may also note that crops produce better around tree stumps than elsewhere in fields. Differences in soil fertility as demonstrated by *in situ* crop productivity differences at varying distances from the tree are discussed later in this chapter.

Savanna tree species

Soil chemical analyses beneath savanna trees in semi-arid zones reveal a common pattern of higher soil fertility under isolated tree canopies than in the open. Fertilizer addition in Kenyan savannas resulted in significantly increased herbaceous productivity in open sites and showed that these soils were nutrient-limited. In contrast, there was no effect on productivity in sub-canopy zones. This suggests that savanna trees were responsible for nutrient enrichment on sites previously poor in nutrients (Belsky, 1994). Nutrient values in relation to distance from woody plants are presented in Breman and Kessler (1995: 156-9). Most studies reported significantly higher content of organic carbon, nitrogen, phosphorus and potassium in the sub-crown environment than in the open (Belsky *et al.*, 1989; Dunham, 1991; Kamara and Haque, 1992). Concentrations of cations such as magnesium, calcium and potassium, and cation exchange capacity (CEC) were also higher under tree cover (Belsky *et al.*, 1993; Isichei and Muoghalu, 1992). In general, concentrations of these elements gradually decline with increasing distance from the tree bole, as well as with increasing soil depth (Barth and Klemmedson, 1978; Bernhard-Reversat, 1982; Kellman, 1979; Vetaas, 1992).

Parkland tree species

Nutrient concentrations under *F. albida* are generally significantly higher than in the open (Table 3.1). The tree effect is variable, however, and subject to several factors including land form, soil type, tree density and management practices. First, it is generally more pronounced in upland sites where soils tend to be more gravelly, shallower and less fertile than in the richer bottomland locations (Depommier *et al.*, 1992; Saka *et al.*, 1994). On the rich alluvial soils of the lakeshore plain of Malawi, soil nutrient status showed no difference under and away from *F. albida* trees, probably because the influence of trees is masked by the high natural site fertility and the effect of tillage practices (Rhoades, 1995). In the deep eutrophic soils of Dossi, Burkina Faso, the lack of tree-related nutrient difference was attributed to the regular and abundant application of livestock manure, as well as the fairly high and regular density

Table 3.1 Improvement (%) of soil nutrient content under *Faidherbia albida* canopies compared to controls in the open

Source	Carbon	Total Nitrogen	Average Phosphorus	Exch. Potassium	Calcium	Magnesium	Sodium	CEC saturation	Base	Texture
Charreau and Vidal, 1965 (0-10 cm)	62	94	134	43	100	78	33	47	25	7 Clay + silt
Dancette and Poulain, 1969 (0-20 cm)	37	33	32	n.s.	43	n.s.	n.s.	n.s.	19	0
Jung, 1966 (cited in Gelger *et al.*, 1994)	100	100	-	-	-	-	-	120	-	52
Jung, 1969	-	156	57	45	270	53	-	-	-	-
Oliver *et al.*, 1996 (0-20 cm)	11-86	15-107	18-36	70-115	2-47	0-33	-	8-47	-	-
Seyler, 1993 (0-20 cm)	38 (OM)	60	60	133	28	36	-	-	-	-

n.s. = not significant
OM = Organic matter

of large *Faidherbia* tree crowns, all of which contribute to spreading out the fertility influence related to trees (Depommier, 1996a). Soil fertility under crowns also varies with the intensity of tree pruning, estimated to remove 50 to 100 kg of dry matter of leaves and twigs, some of which is recovered under tree cover in animal droppings.

Nutrient enrichment under other parkland trees may be less remarkable than for *F. albida* but is also common. Kater *et al.* (1992), for example, found higher carbon, available magnesium and potassium contents in the upper soil layers under both *P. biglobosa* and *V. paradoxa* canopies than in the open. However, phosphorus availability was greater away from trees. This may reflect a lower phosphorus uptake due to a lower root density (Tomlinson *et al.*, 1995). Jonsson (1995) reported higher exchangeable potassium and higher pH under *V. paradoxa* trees than in open field controls in Saponé, Burkina Faso. In addition, the fraction of carbon derived from C_3 plants (which reflects the effect of trees (C plants) in C-plant dominated systems)[1] was significantly higher in the proximity of both *Vitellaria* and *Parkia* trees than in treeless areas. The C_3-plant carbon contribution was 30 percent higher under *P. biglobosa* than in the open (Jonsson, 1995). Areas outside *Vitellaria* canopies were also characterized by a slight but significant higher organic carbon, potassium and pH than zones at mid-distance between trees in southern Burkina Faso (Boffa *et al.*, forthcoming). In Mali, *Vitellaria* sites were associated with higher content of exchangeable calcium and magnesium than treeless locations, while the opposite was true for aluminium (Diakité, 1995). In a sample of 54 trees located in Burkina Faso and Nigeria, total nitrogen and available potassium were significantly improved under *P. biglobosa* (Tomlinson *et al.*, 1995). Organic carbon, total nitrogen, available phosphorus, exchangeable calcium and CEC were respectively 57, 61, 47, 22 and 15 percent higher under *Cordyla pinnata* cover than outside in Senegal (Samba, 1997). In Kareygorou and Say, Niger, soil pH, organic matter content, total nitrogen, available phosphorus, exchangeable potassium, magnesium and calcium were significantly higher under *Hyphaene thebaica* (and *F. albida*) than in the open and decreased with distance from trees (Moussa, 1997). Soils under *Prosopis africana* contained a higher concentration of

[1] C_3 and C_4 plants have slightly different photosynthetic (carbon dioxide fixation) mechanisms, with the C_4 process particularly adapated to high light intensities and temperatures. Most C_4 species are monocotyledons and they include the majority of savanna grasses and cereal crops (except rice), while trees and other dicotyledonous species tend to use the C_3 mechanism.

total nitrogen and exchangeable bases (particularly magnesium and potassium), and had a better pH and CEC (Bernard, 1996).

Trees significantly influence the fertility of tropical soils by maintaining soil organic matter. Cation exchange capacity is primarily determined by clay content and mineralogical composition. However, organic carbon provides much of the CEC of tropical soils which are based on kaolinite clays rich in iron and aluminium oxides and hydroxides (Jones, 1971; Pichot, 1975; Kater *et al.*, 1992). Furthermore, organic carbon also has a greater influence on the size of the exchange complex and soil cations on sandy soils than on fine-textured ones (Campbell *et al.*, 1994).

Orientation sometimes has a significant impact on soil nutrient content due to the action of dominant winds or asymmetrical crown distribution on accumulation of organic matter. For instance, organic carbon, pH, calcium and magnesium were all significantly higher in soils located to the west of *V. paradoxa* trees than to the east in Mali, where northeastern harmattan winds prevail (Diakité, 1995). Higher moisture in an Ethiopian vertisol was also recorded on the west side of *F. albida* crowns, probably as a response to wind-accumulated litter (Kamara and Haque, 1992). In Malawi, nitrogen was mineralized more rapidly on the north and east sides of large *F. albida* canopies compared to the south, due to the fact that canopy volume is greater on the north side of trees where the sun trajectory is during the growing season (Rhoades, 1995).

Tree species affect the nutrient content of soils in different ways. For instance, in south Mali, soils (0 to 40 cm horizon) under *P. biglobosa* trees had a lower pH and less available calcium and magnesium than under *V. paradoxa* trees (Kater *et al.*, 1992). Likewise, higher Mg content and acidity were reported on *Adansonia digitata* sites than under *Acacia tortilis* in Kenya (Belsky *et al.*, 1989). Nutrient content of leaves, the extent of nutrient reabsorption prior to leaf abscission, and amounts of litterfall influence nutrient concentration in litter (Vitousek and Sanford, 1986, cited in Rhoades, 1995).

Fig. 3.1 ***Vitellaria paradoxa*** **(right) and** ***Parkia biglobosa*** **(left) parkland in the Bassila region of Benin**
K. Schreckenberg

Influence of trees on mineral content of understorey plants

The generally higher soil nutrient status under tree cover is reflected in the mineral content of understorey herbaceous species. In northern Senegal, nitrogen content of aerial herb parts was higher under *Acacia senegal* and *Balanites aegyptiaca* than in the open. It also decreased more slowly during the rainy season under trees than in the open (Bernhard-Reversat, 1982). Under *F. albida* in Senegal, concentrations of all mineral elements except insoluble ash and sulphur in millet leaves were 25 to 40 percent higher than in the open. Protein content of millet grain increased by 32 percent under *F. albida*, and by 242 percent on a kg/ha basis, due to the grain yield increase related to the presence of trees (Table 3.2) (Charreau and Vidal, 1965). Nutrient concentrations were also higher in millet grown under *F. albida* than in the open in N'dounga, Niger (ICRAF, 1996). A 54 percent increase in nitrogen and a smaller but significant difference in available phosphorus were recorded. In Nigerian savannas, however, no significant differences in mean crude protein, fibre and lignin content were observed between forb species growing under tree canopy

Table 3.2 Crop yields under and outside *Faidherbia albida* canopies

Crop	Grain yield (kg/ha)				Biomass yield (kg/ha)				Source
	1a	2a	Diff.b (%)	Stat. Sig.	1	2	Diff. (%)	Stat. Sig.	
Millet	660	1668	+153	0.01					Charreau & Vidal, 1965
Millet	645	1044c	+62	<0.05	-	-	-	-	Louppe *et al.*, 1996
Millet	1008	1506	+49	-					Maïga, in Kessler, 1992
Millet							+36d	0.024	ICRAF, 1996
Sorghum	457	934	+104	0.001	5480	10940	+100	0.001	Dancette & Poulain, 1969
Sorghum, fertilizer	1340	1388	+3	n.s.	15870	18140	+14	0.1	Dancette & Poulain, 1969
Sorghum	1570	2130	+36e	<0.05	97 g/pl.	145	+49	<0.01	Poschen, 1986
Sorghum	197	529	+169	<0.05	1538	2607	+70	n.s.	Depommier *et al.*, 1992
Sorghum	671	1674	+149	<0.05	2717	3855	+42	<0.05	Depommier *et al.*, 1992
Sorghum	898	1797	+100	<0.05	2207	4356	+97	<0.05	Depommier *et al.*, 1992
Sorghum	889	937	+5	-					Maïga, in Kessler, 1992
Maize (local)	-	-	+42-272	-	-	-	-	-	Saka *et al.*, 1994
Maize (hybrid)	-	-	+76-78	-	-	-	-	-	Saka *et al.*, 1994
Maize	1920	3390	+76e	<0.01	53 g/pl.	66	+24	n.s.	Poschen, 1986
Maize	-	-	+27	<0.05	-	-	+22	<0.05	Depommier, 1996a
Groundnut	1181	1052c	-11	n.s.	990	1382c	+40	<0.05	Louppe *et al.*, 1996
Groundnut, manure	1289	992c	-23	n.s.	1492	1459c	-2	n.s.	Louppe *et al.*, 1996
Groundnut (Patar 1)	1373	1300	-5	-	1155	1221	+6	-	IRHO, 1966
Groundnut (Patar 2)	1131	1537	+36	-	874	1080	+24	-	IRHO, 1966
Groundnut (Marnane 1)	1067	1532	+43	-	924	1283	+39	-	IRHO, 1966
Groundnut (Marnane 2)	1592	1541	-3	-	1205	1061	-12	-	IRHO, 1966
Groundnut	810	1108	+37	0.01	860	1266	+47	0.001	Dancette & Poulain, 1966, in CTFT, 1988
Groundnut, fertilizer	954	1136	+19	0.1	1091	1386	+27	0.01	Dancette & Poulain, 1966, in CTFT, 1988

Notes: a 1=open controls; 2=sub-canopy plots
b Difference = ((sub-canopy yield - open field control yield) / open field control yield)) x100
c Average over the whole sub-canopy area
d Total biomass
e Although smaller than West African values in relative terms, Poschen's (1986) sorghum and maize yield improvements in Ethiopia are higher in absolute terms because his control values are about twice as high as West African ones.

and in the open (Muoghalu and Isichei, 1991). It should be remembered that, in order to monitor the tree effect correctly, account should be taken of the variation in understorey biomass, which depends on moisture availability, to some extent irrespective of mineral plant nutrition. Mineral elements can often be diluted with an increase in biomass.

Mechanisms of soil fertility improvement

Comparative increases in nutrient content are highly significant under **Faidherbia albida** ***trees, and less remarkable though still common in other parkland species.***

Several factors contribute to the fact that soils under the cover of parkland trees have a higher fertility status than in the open field. These include soil microbial activity, atmospheric inputs, nitrogen fixation, dung deposition, pre-existing soil fertility and soil management practices.

Soil microbial activity and structure

The primary processes held responsible for the formation of high fertility islands around trees relate to enhanced biological processes associated with the seasonal and long-term return of nutrients accumulated in trees to the soil through litterfall, root decay and exudation, and their mineralization, as well as leaching of nutrients stored in canopies.

Box 3.1
Influence of parkland trees on soil texture

Several studies report a higher clay and silt content near *Faidherbia albida* trunks than in the open (Table 3.1) (Charreau and Vidal, 1965; Jung, 1966, cited in Geiger *et al.*, 1994). This was also the case in the proximity of *Vitellaria paradoxa* trees in Mounzou, Mali. Percentages of fine and total silt were respectively 26.9 and 38 percent at a distance of half a canopy radius, and 25.6 and 36.3 percent at a distance of three canopy radii (Diakité, 1995). Charreau and Vidal (1965) attributed this phenomenon to the lower levels of soil erosion under tree cover, the preference of tree sites by termites which bring fine elements to the surface, or the fact that *F. albida* regenerates more easily in areas affected by termites or clay-rich zones. Available evidence in Cameroon indicates that erosion under and outside tree cover (ranging from 2.4 to 14 t/ha), as well as run-off for rains of 11 mm and above, was not significantly different under and away from *F. albida* trees (Libert and Eyog-Matig, 1996). It is more probable that the finer texture is the result of termite activity, which is associated with higher clay and soil organic matter contents (Brouwer *et al.*, 1992). The presence of old termite mounds was a probable reason for the striking difference in clay content in horizons 20-30 to 140 cm deep between poor and good *F. albida* growth sites in Niger. This also suggests that such sites could provide tree seedlings with higher survival and growth conditions and that the so-called '*Faidherbia albida* effect' could be partly due to pre-existing fertility patterns (Geiger *et al.*, 1994). Finally, a higher content of fine-textured elements may also result from the capture of windborne soil particles by tree canopies and their input to the soil through rainfall and litterfall.

Soil texture sometimes differs according to tree size. In Mounzou, Mali, Diakité (1995) observed a significantly higher clay content (34.7 percent) in the proximity of smaller (crown diameter 9.9 m) trees than around larger (15.4 m) trees (32.6 percent). Concurrently, there was a lower total silt content around small trees than near large ones. A higher content of fine soil particles under small (35 cm dbh) *F. albida* than large (86 cm dbh) ones was also reported in Cameroon on a small sample (Libert and Eyog-Matig, 1996). Reasons behind these variations related to tree size are not clearly understood. Based on the potential mechanisms affecting textural changes presented above, one would have expected, for example, that increasing crown height and width would lead to a larger capture of windborne particles, and thus a higher concentration of fine elements.

Increases in organic matter and improved microclimatic conditions under parkland (and savanna) trees enhance soil microbial and enzymatic activity, decomposition and physical characteristics. Compared to open sites, biological activity is two to three times higher under *F. albida* which loses its leaves at a time when conditions for microorganisms are favourable (Jung, 1970). In Kenya, Belsky *et al.* (1989) found 35-60 percent higher soil microbial biomass-carbon, lower bulk density of top soils, and higher water infiltration rates under *Adansonia digitata* and *Acacia tortilis* crowns than in the open. Increased macrofauna and soil organic matter under tree clumps were associated with improved soil macroporosity and lower bulk density in Côte d'Ivoire (Mordelet *et al.*, 1993, cited in Rhoades, 1997). Higher activity of macrofauna such as termites may also be one of the factors responsible for changes in textural properties of soils at tree sites (see Box 3.1).

Rates of nitrogen mineralization are also higher under tree canopies than in the open, with an intense flush during the first few weeks of the rainy season (Jung, 1970; Belsky *et al.*, 1989). Soils under *F. albida* in Malawi contained 7 times more plant-available nitrogen than in the open during the first month of the rainy season, and 1.5 to 3 times more during the rest of the cropping season (Rhoades, 1995). This phenomenon was also observed by Depommier (1996a) early in the rainy season in Burkina Faso. However, although the early rainy season peak of mineralized nitrogen, which is predominantly in the highly mobile nitrate form, is potentially beneficial to young plants, it may be leached to a large extent before crop roots have developed sufficiently to absorb it. Rhoades (1997) therefore recommends mixing *F. albida* leaf litter with lower quality (high carbon:nitrogen) plant material in order to obtain a more gradual nutrient release.

Atmospheric inputs

Fine soil lost through wind erosion may be intercepted by trees and deposited by throughfall and stemflow. It was calculated that an annual rate of 1.2 kg/ha of phosphorus is deposited with dust from the Sahara 1 000 to 1 200 km away (McTamish and Walker, 1982, cited in Kessler and Breman, 1991). Dust deposition may be particularly important in species retaining their foliage during the dry season when strong harmattan winds prevail. Studies comparing nutrient concentrations in rainwater in the open and in throughfall detect differences. For instance, nitrogen enrichment of 0.53 g/m^2 was measured beneath *Acacia senegal* (Bernhardt-Reversat, 1982). In contrast, no difference was noted in mineral nitrogen content between rainwater collected under *F. albida* canopies and in the open (Jung, 1969). Similar tests in Saria, Burkina Faso, revealed that *V. paradoxa* canopies had absorbed nitrogen and maybe phosphorus, from rainwater and released potassium, organic carbon, calcium and magnesium (Roose *et al.*, 1974). These studies do not, however, specify whether these nutrients are recycled through leaching or added to the system by atmospheric deposition.

Nitrogen fixation

Trees also increase soil nitrogen availability due to N-fixation. However, Dommergues (1987) assessed the N-fixation potential of legumes in West Africa to be lower than expected. One reason is that few woody species have been reported to nodulate naturally in the Sahel and Sudan zones of West Africa. While nodulation is common for *F. albida* seedlings, N-fixation is rarely reported in adult trees (Dunham, 1991; Giffard, 1971). Therefore, the contribution of increased soil nitrogen under *F. albida* due to N-fixation is limited (CTFT, 1988). An absence of nodules was also noted in roots of mature *Acacia senegal* trees (Bernhardt-

Reversat, 1982). N-fixation in forest stands may in reality be important when trees are young and is considerably reduced with increasing stand age when the pool of soil nitrogen is sufficient to supply them (Dommergues, 1995). One could hypothesize that some degree of N-fixation continues into adult tree age in agroforestry parklands, where nitrogen is extracted by crops and mostly not returned to the soil (Harmand, 1998).

The lack of difference in soil nitrogen beneath *Adansonia digitata* and the leguminous *Acacia tortilis* indicated that nitrogen enrichment under these trees was not related to N-fixation (Belsky, 1994). Other leguminous parkland species such as *P. biglobosa* do not nodulate in the field or in the greenhouse. However, 85 percent of this species' roots are infected with endomycorrhizae regardless of location and tree size, suggesting an increased nutrient uptake capacity of the tree (Tomlinson *et al.*, 1995). N-fixation is mostly limited by low availability of phosphorus, which is one of the most common nutrients limiting plant production in semi-arid regions (Penning de Vries and Djitèye, 1991). Finally, Breman and Kessler (1995) argue that no evidence points to an increase of nitrogen yields or concentrations in associated herbs and crops with increased cover of woody legumes over a north-south regional gradient, and conclude that fixed nitrogen is mostly utilized by the woody plants themselves. More recently, experiments in Cameroon have demonstrated that this process may occur on a local scale (Harmand, 1998).

Dung deposition

Increased fertility under trees may also be due to bird droppings and, in parkland systems which integrate livestock, dung deposition by animals which rest and feed under tree shade (Belsky *et al.*, 1989). In Burkina Faso, the average amount of faeces deposited by cattle under *F. albida* crowns was higher than in the open field by only 11 percent in Dossi but up to 180 percent in Watinoma (Depommier, 1996a). The spatial variability of organic inputs by cattle, compounded by horizontal movements through runoff and floods which depend on topography, tends to generate differences in nutrient content observed between sub-canopy and open sites. Where livestock is a significant component of farming systems, its contribution to the overall soil fertility improvement of *Faidherbia* tree is probably considerable and should be specifically assessed. However, nutrient enrichment under *F. albida* was also demonstrated in the absence of livestock influence in Senegal (Charreau and Vidal, 1965). The tree effect may be more pronounced where livestock is excluded than in natural agrosylvipastoral systems (Poulain, 1984, cited in CTFT, 1988).

Pre-existing soil fertility

Higher fertility of tree sites has also been attributed to pre-existing soil fertility variations, which can occur at several scales. Variations at the village level are consistent with farmer practices of identifying fertile soils to be cleared for cultivation based on local vegetation characteristics. A high density of individual woody species, such as *Isoberlinia doka, Pterocarpus erinaceus, Detarium microcarpum, Prosopis africana, Piliostigma sp.* and *Pteleopsis suberosa*, (Bagnoud, 1991 and 1992, in Cissé, 1995), as well as grasses, and green and dense foliage are typical fertility indicators. In addition, in a *F. albida* trial in Niger, Geiger and colleagues (1994) observed that areas of good *F. albida* growth were associated with favourable microsite soil physical and chemical conditions. They suggested that these fertility characteristics, present before tree establishment, may be partly responsible for the

high productivity found under mature *F. albida* trees. In Malawi, the positive impact of large *F. albida* trees on nitrogen mineralization rates, soil moisture increase and content of exchangeable cations was not noted for small trees. This led Rhoades (1995) to conclude that improved crop yields under large trees resulted from the combined tree effect on microclimate and the influence of litter/root inputs on soil nutrient availability, rather than patterns of pre-existing soil fertility. While it has mostly been studied for *F. albida*, pre-existing soil fertility could also apply for other species.

Soil management practices

Finally, fertility variations under and outside of trees can be related to human activities. Due to the absence of, or limited, cropping, there may be a higher soil fertility status under *P. biglobosa* (Kessler, 1992). Weed production is generally increased under parkland trees and more intense weeding is needed (Libert and Eyog-Matig, 1996).

Nutrient enrichment with increasing tree size

Small trees induce little fertility change in their soil environment. Kellman (1979) found that no significant nutrient enrichment could be found under *Pinus caribaea* saplings in a neotropical savanna of Belize. The process of soil amelioration under trees results from the trees' ability to establish a plant-litter-soil nutrient cycle which increases with time (Kellman, 1979). In Malawi, small (6.6 m in crown diameter) *F. albida* trees did not increase net nitrogen mineralization rates relative to open sites. In contrast, larger canopies (24 m) resulted in 170 percent more nitrogen production during the growing season than in the open field (Rhoades, 1995). With less than one-tenth of the canopy area of larger trees, small trees produced significantly less organic litter and root turnover inputs. Unlike larger trees, small ones also had no dung deposited beneath them.

Fig. 3.2 Crop and clearing residues are gathered and burned before the next agricultural season
J.-M. Boffa

Other reports also suggest that nutrient enrichment by trees increases with tree size. Bernhard-Reversat (1982) showed a clear, positive relationship between tree diameter and carbon and nitrogen content in soil under crowns of *Acacia senegal* and *Balanites aegyptiaca* in northern Senegal. Higher values of soil chemical variables were also detected under as opposed to outside canopies of 10-year and older saplings in a tropical dry forest of Mozambique (Campbell *et al.*, 1990). In savannas of northwestern Nigeria, soils under trees above 7 m in height had higher concentrations of organic matter, exchangeable cations, clay and silt than under trees smaller than 7 m (Isichei and Muoghalu, 1992). Concentration of exchangeable cations (calcium, magnesium, potassium and sodium) around small *F. albida* trees was considerably lower than in the proximity of large trees in Malawi (Rhoades, 1995). In Tanzania, *F. albida* had no visible effect on intercropped maize and bean yields from one to six years after establishment, at which point it averaged 9 m in height (Okorio and Maghembe, 1994). Once *F. albida* trees mature, tree size has a favourable effect and is correlated with grain yield productivity, probably due to a larger input of litter (Depommier *et al.*, 1992). The '*Faidherbia albida* effect' may require 20 to 40 years to become evident, depending on the growth rate of individual trees (Poschen, 1986). Improvement of nitrogen and potassium content under *P. biglobosa* crowns also increases with tree size (Tomlinson *et al.*, 1995).

The process of soil amelioration under tree results from the tree' ability to establish a plant-litter-soil nutrient cycle.

These references show that young trees do not seem to influence the size of the nutrient pool significantly, and that the nutrient concentration of sub-canopy soils expands with tree size. More specific information is needed on the dynamics of soil fertility with increasing tree size in relation to the performance of associated crops, and recommendations on size/age and related conditions of tree stands from which increased nutrient availability can potentially generate enhanced crop yields.

Parkland density and soil fertility

Most studies reviewed in this chapter take place at the scale of individual trees. However, a comprehensive assessment of the system also requires comparisons at the scale of a plot with two or more trees, a field or a land form unit. This section presents this level of analysis with respect to soil fertility, with crop yields and microclimate being dealt with in later sections. While nutrients may be concentrated in tree sites through various pathways, processes such as litterfall, decay of lateral roots, activity of macrofauna, transport of organic debris through water runoff and wind, as well as lateral movement of parkland-derived organic matter through cattle droppings and soil management practices, may involve the movement of nutrients from trees to the open field.

It could be hypothesized that the 'parkland effect' (i.e. more than one tree) on soil fertility in the open field may become detectable over a given range of tree density. This range may be intermediate between treeless agricultural soils whose stock of organic matter and fertility are gradually impoverished under continuous cultivation (Taonda, 1995), and soils under fallow which allow for the biological pumping of mineral elements and the restoration of organic matter in topsoil (Harmand, 1998). For instance, Depommier (1996a) argued that the high density and regular arrangement of *F. albida* trees in Dossi could, among other factors, contribute to the lack of difference in nutrient concentration in subcanopy and open soils.

Data relating tree density and soil nutrient status in savanna or parkland situations are relatively scarce and inconclusive. Total nitrogen in the 0-15 cm horizon was significantly positively correlated with tree density in Nigeria (Sanford *et al.*, 1982). The fact that soil productivity in the Peanut Basin in Senegal depends almost

entirely on soil organic matter content led Seyler (1993) to postulate that farmers manage the woody component in fields to manipulate the organic matter and nutrient content of soils. Based on samples in the 0-20 cm horizon at 20 m from *F. albida* crowns on four soil types, no significant relationship was found between cover of *F. albida* or other woody species in sample fields and soil organic matter in the open. When considering total parkland cover, the relationship was only slightly strengthened. The effect of tree density on soil organic matter content in open areas was not apparent in this study of limited sample size.

The high variability in fertility among tropical soils, even within a field, and the two-dimensional scale of sampling units including more than one tree at a time pose an important challenge in studying the fertility-density relationship. GIS and modelling technologies may facilitate processing and representation of such data needed to advance understanding of this particular area.

Kessler and Breman (1991) caution that attempts to increase parkland density should evaluate processes which influence nutrient availability in these systems (see next section). Where trees improve understorey soil nutrient content through spatial redistribution, maximum tree densities are determined by the overall size of the system's nutrient pool.

There may have a positive 'parkland effect' on crop production linked to the spatial arrangement of scattered parkland trees.

Nutrient redistribution versus enrichment

Whether trees only act to redistribute nutrients already available in the system or actually increase nutrient availability is central to determining when and how integrating trees in cropping systems is beneficial. While the way each component may relate to the processes at play in overall nutrient dynamics is conceptually well established, the quantification of these processes remains limited.

Some researchers think that higher fertility close to trees results from nutrient redistribution and spatial concentration around woody plants through lateral uptake by roots, animal deposition, and wet and dry atmospheric deposition (redistribution on a larger scale) (Kessler and Breman, 1991; Kater *et al.*, 1992; Tomlinson *et al.*, 1995). A large number of investigators prefer to emphasize the importance of enhanced biological recycling of organic matter in higher system productivity. The only experiment identified in the literature reviewed, which challenges nutrient redistribution through lateral root uptake, originates in Matopos, Zimbabwe, where similar fertility patterns were found at natural savanna sites and on soils which have been experimentally managed with trenches since 1963. From this, Campbell and collaborators (1994) concluded that fertility under trees was not at the expense of fertility decline in the surface soils of the zone around trees. This probably depends on the rooting habits and density of tree species and the characteristics of soil profiles.

Trees may also increase system productivity by reducing nutrient losses through leaching in deep soil, and reduced soil erosion. However, the data necessary to document this process are difficult to obtain. In Mali, the majority of fine *Acacia seyal* and *Sclerocarya birrea* roots were found below those of herbaceous plants. Soumaré *et al.* (1994) therefore suggested that trees might capture nutrients which would have been lost in their absence, and improve efficiency of nutrient use. While leaching is common in humid conditions, however, the process is limited to run-on locations (valleys and water courses) in semi-arid zones (Kessler and Breman, 1991). The available yet limited data from northern Cameroon suggest that parkland trees do not reduce soil erosion significantly (Libert and Eyog-Matig, 1996).

Fig. 3.3 Cattle grazing on *Prosopis africana* pods in cotton fields, Holom, northern Cameroon
C. Bernard

Finally, trees may increase overall system productivity by increasing nutrient availability through N-fixation (as discussed earlier) and deep rooting, and their enlarged absorptive capacity associated with mycorrhizal and fungal infection. However, even though these processes may be important in particular sites with appropriate soil conditions and water availability, there are limitations to these processes in the Sahel and Sudan zones.

The deep penetration of tree roots is often highlighted as being important in the role of trees as nutrient pumps (Young, 1989). Tree roots are assumed to capture nutrients in deep soil layers made available by weathering of the bedrock and those leached down from upper layers. Yet this process may not always be significant. The highest concentrations of available nutrients, for example, are found in the topsoil; the subsoil's nutrient content is low (Kellman, 1979). Few nutrients are made available following weathering in already intensely weathered soils (Breman and Kessler, 1995). In the case of phosphorus, which limits primary production and whose mobility is low due to its high apparent adsorption constant, Breman and Kessler (1995) argue that, if weathering and subsequent uptake by deep tree roots were significant, one would find a correlation between phosphorus yield in herbage biomass and woody cover. Such a correlation was not found along a transect from the northern Sahel to the southern Sudan zones. Furthermore, the impact of leaching decreases in importance as aridity increases (Kessler and Breman, 1991). Finally, water infiltration to the subsoil is limited, and shallow plinthite pans (CILSS, 1981 and 1982, cited in Breman and Kessler, 1995) and chemical root barriers (acidity, salinity, aluminium or manganese toxicity, and phosphorus and calcium deficiency) are common in semi-arid areas (Szott *et al.*, 1991).

Underground tree-crop interactions

Understanding the nature of interactions between trees and crops is of major importance in determining approaches to tree management in parklands. Savanna tree-grass interactions have been understood in a two-layer model which emphasizes that grasses have a root system confined to the upper soil and tree roots extend to deeper soil layers, thus minimizing the competition between the two (Walter, 1971; Walker and Noy-Meir, 1982). Other studies further suggested facilitation between woody and herbaceous plants, whereby trees improve soil nutrient content and herbage production, and affect the composition of herbaceous species nearby (Radwanski and Wickens, 1967; Kennard and Walker, 1973). It is now recognized that grasses and trees have a respective competitive advantage in capturing water and nutrients from the upper and lower soil horizons, yet herbaceous roots also extend into deep soil layers (Knoop and Walker, 1985). This suggests that competition and facilitation occur together in agroforestry, with variations in outcome according to habitat and tree species.

Numerous studies report the co-occurrence of tree and grass/crop roots throughout soil profiles (Belsky, 1994; Knoop and Walker, 1985; Jonsson *et al.*,

1988). Generally speaking, the lateral spread of roots tends to be concentrated in the canopy area in humid zones, whereas they extend far beyond this area in more arid zones in order to acquire adequate supplies of soil moisture (Breman and Kessler, 1995). In a dry area of Kenya (450 mm rainfall), severing roots in the canopy zone by trenching did not alter understorey productivity substantially. But this was probably due to the fact that the sub-canopy roots were large rather than fine absorptive roots and did not compete with the herbaceous vegetation. Since trenching also had no effect in the open, Belsky (1994) believed that areas explored by fine absorptive roots located at the end of large, long roots in mature trees might have been overlooked in view of the spatial dispersion of these roots. Overall, the positive soil nutrient and microclimate effects of trees on understorey productivity exceeded the depressive effect of competition. In contrast, in higher rainfall (800 mm) areas, tree roots may explore a smaller area restricted within or shortly outside tree crowns where soil fertility is high. Trenching under tree crowns in mesic conditions often results in the increase of understorey productivity (Belsky, 1994).

Underground competition between unpruned *F. albida* and crops is thought to be small because of its dry-season physiological cycle of growth and its deep tap roots. This is consistent with the crop productivity gains under this species reviewed later. But the number of below-ground interaction studies remains limited. Deep rooting is common for this species as its growth has to rely on dry-season reserves. A three-year old *F. albida* excavated near Kano, Nigeria, had a vertical root shaft of over 10 m (Weber and Hoskins, 1983). In Tanzania, *F. albida* had no effect on maize and beans during the first six years of intercropping even at 4 x 4 m spacing (Okorio and Maghembe, 1994). In northern Cameroon, *F. albida* roots were not present in the 80 cm soil depth of cotton root extension. Available water content in soils measured by moisture probes was higher under trees at the beginning and end of the season but

Box 3.2

Pruning modifies Faidherbia albida's reverse foliation patterns

The leafless condition of *Faidherbia albida* in the wet season is the most remarkable feature of the species. However, research shows that it does not apply systematically in the case of pruned trees, as pruning causes a significant disturbance in the species' natural phenology (Depommier, 1998). In Watinoma, Burkina Faso, traditional pruning carried out by herders in the late part of the dry season stimulated refoliation peaks of variable duration and intensity during the agricultural season. With more drastic pruning, refoliation was more intense and its period extended. When subject to total artificial crown reduction, a rapid and complete refoliation caused trees to remain in leaf throughout the agricultural season in Dossi, Burkina Faso, and the shedding of leaves to be delayed by three to four months. With little delay, pruned trees then display a new foliation phase, which is roughly synchronous to that of unpruned trees. Pruning, which is often practised to some degree in the Sahel, can thus substantially shorten or even virtually cancel the period of reverse foliation for which the species is so well known.

A few other studies report *F. albida* in leaf during the agricultural season, presumably as a result of some degree of pruning. For instance, Libert and Eyog-Matig (1996) found that two out of four trees maintained 50 to 100 percent of their foliage during the whole cropping season in northern Cameroon. *Faidherbia albida* in maize and green gram intercropping studies in Kenya also did not shed their leaves during the dry season. Individual genetic variability in phenology as well as events such as insect attacks and fire, or even a drought period during the wet season, which have been shown to induce a second foliation (Dunham, 1991; Depommier, 1998), may also cause *F. albida* to be partially in leaf during the agricultural season. Otherwise, the reverse phenology of the species appears to conform to seasonal cycles, and particularly the starting date, abundance, and duration of rainfall. Site and tree size effects had little impact on the phenological phases of unpruned trees in Dossi.

was little affected by the trees. Libert and Eyog-Matig (1996) concluded that the negative impact of *F. albida* on cotton production was due to shade rather than root competition.

Extended foliation during the rainy season caused by intense pruning (Box 3.2) prolongs *Faidherbia*'s growth season (Depommier and Detienne, 1996) and may increase underground competition with crops for nutrients. However, given that farmers made no mention of it, any negative (above and underground) impact of trees in leaf during the rainy season on understorey crops may be insignificant compared with its otherwise positive fertility effects (Depommier, 1998). More detailed investigations into the effect of pruning on underground interactions would be desirable.

Lateral root systems of species with normal leaf phenology are likely to cause competition with crops in parklands. Large roots of *V. paradoxa* and *P. biglobosa* were found 60 m away from the trunk (Jonsson, 1995). The extensive lateral root system of *P. biglobosa* covered an area eight times that of the crown (Tomlinson *et al.*, 1995). This species appears to display a more superficial rooting than *V. paradoxa* and results in more intense competition with crops (Kater *et al.*, 1992). In Niono, Mali, the root system of *Acacia seyal* had a thin, deep taproot which could reach 6 m in depth, while lateral roots were concentrated in the upper 40 cm of soil and extended a distance of 5.6 times the average canopy radius. *Sclerocarya birrea* roots extended 2.4 m in depth and 7.4 times the average crown radius in the top 60 cm of soil (Soumaré *et al.*, 1994). So far, the depressive effect of tree-crop competition and its spatial patterns have not been clearly measured and demonstrated in agroforestry parklands. Understorey crop (especially cereal) production seems to suffer more from the negative effect of shade from trees other than leafless *F. albida*. The specific effect of underground competition in tree-crop interactions needs to be isolated. Additional knowledge about the spatial patterns and functions of tree roots in parklands of distinct rainfall regions will help define the spatial variation of underground competition.

Relations between woody and herbaceous plants

This section reviews available data on the influence of woody plants on the biomass and grain production of herbaceous plants. Box 3.3 reviews some of the experimental designs used by different authors.

Influence of trees on biomass productivity

In savannas, herbaceous biomass under woody plants can be higher than in the open. Productivity close to trees and in the interspaces may vary by a factor of 1.5 to 4.5 (Tiedemann and Klemmedson, 1977; Barth and Klemmedson, 1978; Weltzin and Coughenour, 1990; Akpo and Grouzis, 1996; Belsky *et al.*, 1989). A lower productivity under trees has also been reported (Grunow *et al.*, 1980; Jameson, 1967; Somarriba, 1988), however, and other authors observed that removing woody plants increased vegetation yield (Dye and Spear, 1982; Beale, 1973; Ward and Cleghorn, 1964). Belsky (1994) noted that increased understorey productivity is the most common pattern in tropical tree communities with low density, low rainfall and moderate soil fertility. While common for low densities of isolated trees,

Box 3.3
Experimental designs for assessing the influence of trees on crop production

A variety of experimental designs as well as control locations have been used to assess the influence of trees on crop production. Studies compared plant performance in small ($1m^2$) discrete quadrats (Kessler, 1992; Maïga, 1987), or a relatively small number of plants (Kater *et al.*, 1992) at regular intervals from trees, up to a distance of two or three (Diakité, 1995) crown radii. Plots located farthest from the tree trunk within or outside the experimental unit are then used as controls. Alternatively, the experimental design used by Louppe *et al.* (1996), with successive concentric rings around trees to distances up to 10 m, which can be divided in the four cardinal directions, can show yield variations over short distances, and reduce directional biases related to leaf or rain fall. This method also uses sample plots large enough to reduce the effect of micro-variability of soil fertility which is usually high in semi-arid West African soils (Brouwer *et al.*, 1992).

Another study monitored sorghum production in wide transects between pairs of trees (Boffa *et al.*, 1999). The significant differences found between plots immediately beyond tree crowns and in the middle of the field point to the importance of distinguishing the three possible zones of tree-crop interactions, i.e. sub-canopy, outside-canopy and the open field using controls as far away from trees as possible. However, the fact that tree roots may extend to treeless zones up to 50 to 60 m from *P. biglobosa* and *V. paradoxa* trees (Jonsson, 1995) demonstrates that even plots located this far may not be true controls unless trenching is used. Alternatively, the use of extensive treeless areas as controls gives rise to soil similarity constraints.

the pattern of higher understorey herbaceous biomass changes as the density of woody plants changes (see below).

In general, understorey biomass decreases with increasing distance[2] from the bole (Barth and Klemmedson, 1978; Weltzin and Coughenour, 1990). A more pronounced effect of cardinal directions is occasionally reported. For instance, in the study by Coughenour *et al.* (1990), south and west directions were more productive.

Plant biomass of cereals under *F. albida* is significantly higher than in the open (Table 3.2). For cotton only a limited amount of information is available. Height of cotton plants under *F. albida* was greater than in controls away from trees, but plant survival was lower under canopies (Libert and Eyog-Matig, 1996). Overall sub-canopy biomass was not reported, but weed biomass in sub-canopy plots was two to six times higher than in open controls. The difference in productivity between tree-covered and treeless sites is substantially reduced when fertilizer is applied.

Above-ground biomass (straw) productivity under *Vitellaria* and *Parkia* crowns tends to be less depressed than grain yields and sometimes positively influenced. Kessler (1992) reported that plant height of sorghum and millet was negatively affected under both *Vitellaria* and *Parkia* canopies but plant weights were not determined. Biomass measurements under medium-sized *Vitellaria* crowns and outside tree canopies were not significantly different, even though sorghum plant height was significantly lower under crowns (Boffa *et al.*, 1999). Jonsson (1995) found that millet biomass was slightly but not significantly higher under *Parkia* and

[2] Plant biomass according to distance from the bole was described by the following equation: Herbage dry matter $m^{-2} = 74.4\ D^{-0.42}$, where D = distance. The regression coefficient (r^2) = 0.97 (Akpo and Grouzis, 1996).

Vitellaria trees than in control areas in the open located 50 to 60 m from the trees. Variation in crop biomass was also lower under canopies than in the open. Moreover, in Mounzou, Mali, sub-canopy straw yields were higher than in the open on average, yet this was more obvious under the smaller trees (Diakité, 1995). Reduction of total millet biomass was only 0.5 percent under a combination of pruned and unpruned *Cordyla pinnata* trees in the southern part of the Peanut Basin in Senegal (Samba, 1997). In addition, grass production was 6.9 t/ha under *P. biglobosa* canopies compared to 3.3 t/ha outside (Sabiiti and Cobbina, 1992). These results support the fact that plant biomass productivity, especially for C_4 crops, may not be significantly lower under than away from parkland trees, as is often observed for natural vegetation in savannas. The outcome of the interaction is also influenced by several site conditions and tree characteristics.

Among C_3 plants, Louppe (1993) reported that cotton plants were taller and bolls were larger under *Vitellaria* crowns than in the open, much like under *Prosopis africana* (Bernard, 1996), whereas Kater *et al.* (1992) found that the height of cotton plants growing under tree crowns declined slightly.

Influence of trees on grain yields of crops

Because of its unique reverse foliation behaviour and its high potential for Sahelian agrosystems, interest in the effect of *F. albida* on crop performance has been ongoing in the last three decades. More recently attention has been extended to other major parkland species such as *V. paradoxa*, *P. biglobosa* and *Azadirachta indica*.

Faidherbia albida, a tree with reverse leaf phenology

The positive influence of *F. albida* on cereal production is considerable and can result in yield increases of over 100 percent[3] under its canopy compared to open field controls (Table 3.2). As assessed by yield differences between tree sites and interspaces, the tree effect was similar to the effect of the combined application of organic and mineral fertilizer on fertile soils in Bambey, Senegal (Charreau and Vidal, 1965), and was equivalent to improving fertility from that of a poor site to one of good productivity as commonly observed in Sob, Senegal (Louppe *et al.*, 1996).

Soil type, topographic position and fertilization

Cereal productivity increases under *F. albida* are generally more pronounced on soils of low fertility and water availability. In the Sahel and Sudan zones of West Africa, fertility and water availability are strongly related to position in the toposequence. In the Ouahigouya region of Burkina Faso, *F. albida* caused a 78, 64 and 18 percent increase in millet yield on upland lateritic soils, sloping lands, and lowland plots, respectively (GERES-CTFT, 1965). The increase in yields was greater when growing under *F. albida* on low productivity soils (113 percent) than on high productivity plots in Sob, Senegal (62 percent) (Louppe *et al.*, 1996). The difference in sorghum yields between sub-canopy plots and controls was also relatively greater on upland plots than on lowland sites (Depommier *et al.*, 1992). In this last experiment, yields were more variable under trees than outside.

Faidherbia's effect may be particularly remarkable in conditions of low soil fertility, as noted above, in combination with below-average rainfall years. In 1990, a

[3] Tree effect is expressed in percentage as ((sub-canopy yield - open field control yield) / open field control yield))x100

drought year in Watinoma, Burkina Faso, upland sites under *Faidherbia* cover yielded almost three times more than locations in the open (Depommier, 1996a). The food security implications of this *Faidherbia*-based agroforestry practice are therefore highly significant to farmers and justify the strong interest aroused by this species.

The influence of *Faidherbia* trees is most noticeable in the absence of fertilizer application. When fertilizer (60 nitrogen, 80 phosphorus, 60 potassium, 15 sulphur) was applied, the *F. albida* effect on grain yield virtually disappeared and substantially decreased on biomass (Table 3.2) (Dancette and Poulain, 1969). Poschen (1986) also noted a comparative advantage of trees in the absence of manure application and where drainage problems prevailed. In N'dounga, Niger, the application of 180 kg nitrogen per hectare cancelled the *F. albida* effect observed on total millet biomass. This clearly indicates that enhanced nitrogen availability was the major parameter contributing to millet productivity under the tree (ICRAF, 1996).

Distance from the tree

There is no consensus on the distribution of yields in the canopy zone. This may be linked to variations in sampling design and/or pruning intensity. Subcanopy millet yields were highest closest to the trunk (73 percent increase compared to an average 46 percent under the whole crown area) in Sob and gradually decreased towards the crown edge (Louppe *et al.*, 1996; Charreau and Vidal, 1965). In contrast, subcanopy plots furthest from the bole showed highest productivity in the Bazega province of Burkina Faso (Maïga, 1987) and in Malawi (Saka *et al.*, 1994). A similar pattern with low yields next to *Faidherbia* trunks and highest yields at the crown edge and gradually diminishing from there on was observed on sorghum in Dossi and Watinoma (Depommier, 1996a). Extended foliation in the rainy season caused by pruning (Box 3.2), and resulting shade, were held responsible for this grain yield depression next to the trunk.

Yields outside *Faidherbia* canopies are generally intermediate between the crown zone and the open field. The extent to which cereal production is influenced

Fig. 3.4 *Faidherbia albida* parklands are a significant source of fuelwood, especially where trees are regularly pruned
R. Faidutti

beyond the crown appears to depend on the intensity of pruning. Pruning was often more intense in large trees, and the tree effect more pronounced at the edge of smaller trees, in Watinoma (Depommier, 1996a). Based on a regression analysis of bole and crown surface areas on unpruned trees, Louppe *et al.* (1996) estimated that the crown cover of *F. albida* trees in their experiment was reduced to 38 percent of its original area by pruning. The beneficial yet statistically insignificant impact of *Faidherbia* was felt a few metres beyond crown limits. These authors assumed that intense pruning led to a reduction of biomass that would otherwise have been incorporated into soils, and thus affected crop production negatively.

Influence on yield components

Yield components are mutually dependent, and variables measured and reported in the various studies differ so that the tree effect on specific yield components is more difficult to determine. It is also likely to vary locally. In Senegal, Charreau and Vidal (1965) found that the increased number of millet heads per planting hole (86 percent compared with control outside *F. albida*) made a greater contribution than increased grain weight per head (32 percent compared with control outside *F. albida*) to overall yield improvements, but plant density was not measured. In Ethiopia, yield increases resulted from the accumulation of higher grain weight, number of grains/plant and slightly higher plant densities under trees (Poschen, 1986). Trees had a significant positive impact on head weight and weight of grains per head in Sob, Senegal (Louppe *et al.*, 1996).

A rigorous study of yield components may provide information on the effect of trees during stand establishment, tillering, spikelet initiation and flowering and grain filling. Farmer management of initial crop density in relation to parkland trees may be insufficiently stressed. Planting density in the proximity of *F. albida* crowns tended to be higher than in the open in Alemaya for sorghum (Poschen, 1986) and in Sob for millet (Louppe *et al.*, 1996). The opposite trend was reported under *V. paradoxa* trees in Thiougou, southern Burkina Faso, in addition to a relatively higher rate of plant failure under *Vitellaria* in Thiougou (Boffa *et al.*, 1999), and under both *V. paradoxa* and *P. biglobosa* trees in South Mali (Kater e*t al.*, 1992), than in the open.

Available projections of *F. albida*'s influence on total crop yields at field scale include the following:

- +3 percent for millet, -2.4 percent for groundnut in Sob, Senegal with a density of five *F. albida* trees/ha (Louppe *et al.*, 1996);
- +11 to 17 percent in Watinoma, Burkina Faso, with a density of 7 to 19 trees/ha (Oliver *et al.*, 1996).

Influence on cotton

In contrast to the relative abundance of observations of *F. albida* intercropping with cereals, only a few studies are available on cotton associations (Libert and Eyog-Matig, 1996; Ouldra Malai, 1990, cited in Libert and Eyog-Matig, 1996). As opposed to the systematically positive influence of *F. albida* on cereals, cotton's response depends on the fertility status of the sites considered. For isolated trees in Tokombéré, northern Cameroon, the tree effect on cotton growing on relatively poor soils was positive, while competition led to a negative tree effect on more fertile soils (Libert and Eyog-Matig, 1996). The average weight of cotton bolls explained 67 to 72 percent of the variability in yields. Plant height under tree crowns was 24 percent greater on average and less variable than in the open. Trees were also responsible for a 20 percent decrease in plant survival.

Influence on groundnuts

Data on the influence of *F. albida* on groundnut production paint a variable picture (Table 3.2). This is reflected in farmer perceptions. Senegalese farmers were much less unanimous about the positive effect of *F. albida* on groundnuts than in the case of millet (Seyler, 1993). In studies with large enough sample sizes to test statistical significance, pod yields were negatively influenced in Sob, Senegal (Louppe *et al.*, 1996), but positively affected in Silane (Dancette and Poulain's data cited in CTFT, 1988). When positive, the influence of *F. albida* on groundnuts is nevertheless substantially lower than that usually reported on cereals in similar regions (Table 3.2). Groundnut response is related to the difference in soil nutrient levels under and away from trees (IRHO, 1966). Where phosphorus or potassium was shown to be deficient, groundnut yields were higher under *F. albida* than in the open, but they remained unchanged in fertile soils. Lower pod production under *Faidherbia* trees in Sob was attributed to higher nitrogen levels in the soil leading to an increase in stalk biomass at the expense of pods, and to the low potassium and phosphorus content due to insufficient returns of stalks to soils, as well as reduced sun radiation during flowering (Louppe *et al.*, 1996).

The *F. albida* effect on stalks is more commonly positive than on pods for groundnuts. When soil fertility levels are improved through application of fertilizer (Dancette and Poulain's data, 1966, in CTFT 1988) or cattle faeces (Louppe *et al.*, 1996), the difference between sub-canopy and control locations decreases or is reversed.

Vitellaria paradoxa, Parkia biglobosa and other species with typical leaf phenology

Unlike the situation with *F. albida*, the response of cereals to trees with typical leaf phenology, such as *V. paradoxa* and *P. biglobosa*, can be substantially negative (Table 3.3). Yields are generally lowest next to the bole and gradually improve with increasing distance from the trunk (Kessler, 1992). However, the fact that this general pattern does not always prevail raises questions. In

Fig. 3.5 *Vitellaria paradoxa* parkland in the dry season, Thiougou, southern Burkina Faso
J.-M. Boffa

Table 3.3 Impact of *Vitellaria paradoxa* and *Parkia biglobosa* on sub-canopy crop yields (%)[a]

Source	Vitellaria paradoxa				Parkia biglobosa		
	Sorghum	Millet	Maize	Cotton	Sorghum	Millet	Cotton
Kapp, 1987	-50	-50	-	-	-50	-50	-
Maiga's data, (Kessler, 1992)	-35	-35	-	-	-50	-40	-
Kessler, 1992	-50	-	-	-	-70	-	-
Kater *et al.*, 1992	-44	-60	-	-2	-66	-60	-65
Boffa *et al.*, 1999	-10[b]	-	-	-	-	-	-
Jonsson, 1995	-	n.s.	-	-	-	n.s.	-
Diakité, 1995	+26[c]	-	-	-	-	-	-
Louppe, 1993	-	-	+17[d]	-(12-30)[e]	-	-	-

Notes:
[a] Measured by the ratio ((sub-canopy yield - open field control yield) / open field control yield))¥100. It should be noted that experimental designs in the above studies differed, including the location of 'control' plots to measure tree effect.
[b] Difference between sub-canopy plots and plots at mid-transect locations between two trees.
[c] Difference between yields of plots located at half crown radius and at a distance of three crown radii.
[d] This positive ratio was obtained on plots of higher soil fertility.
[e] Difference between the average of the whole sub-canopy zone and the most distant concentric ring.
n.s.= not statistically significant.

Saponé, Burkina Faso, no significant differences were found in millet grain production growing under *Vitellaria* and *Parkia* canopies and in the open (Jonsson, 1995). Furthermore, in Mounzou, Mali, sorghum grain productivity was significantly superior under *Vitellaria* trees than at a distance of three times the canopy radius, but this was more conspicuous under the smaller trees in the experiment (Diakité, 1995).

Soil type

While *F. albida* gives rise to greater yield improvements on soils of low fertility, *V. paradoxa* has a more pronounced negative effect on crop yields on soils of low as opposed to high fertility. For example, cotton yields on low fertility sites are more depressed (-32 percent) than on more fertile locations (-14 percent). The same applies for groundnuts (-20 versus +7 percent) and for maize (Louppe, 1993). *Prosopis*-crop interactions may, however, be more favourable on sites of low soil fertility. While a majority of farmers in Holom, northern Cameroon, declared that the effect of *P. africana* on soils was positive, its effect on cotton was not significant as it was probably concealed by the regular application of fertilizer (Bernard, 1996).

Influence on groundnuts and cotton

The effect of *Vitellaria* and other trees tends to be less severe on C_3 plants than on cereals (Table 3.3). In Côte d'Ivoire, average groundnut yields were 6 percent lower under *Vitellaria* canopies than in the open (Louppe, 1993). Picasso (1984) also reported that *Vitellaria* trees had a negative (but unquantified) impact on groundnut yields within a 4 m radius of the bole (cited in Hall *et al.*, 1996). A 25 percent reduction rate was reported for groundnut yields under *Cordyla pinnata* in Senegal (Samba, 1997). Cotton seems less affected by *Vitellaria* than by *Parkia* (Table 3.3) trees. In Holom, northern Cameroon, there was no significant difference in overall cotton yields under *Prosopis africana* trees and in the open (data collected by Libert in 1990 and analysed by Bernard, 1996).

Distinctions between tree species

The ecological combining ability of trees with given crops is a species-specific characteristic related to branch and root architecture. *Prosopis biglobosa* generally has a more pronounced negative effect on crop production than does *V. paradoxa*. This is the case for sorghum (Maïga in Kessler, 1992; Kessler, 1992; Kater *et al.*, 1992) and to a lesser extent for millet (Maïga in Kessler, 1992) (Table 3.3). This is partly due to the larger size and shape of *P. biglobosa* and different rooting patterns. *Vitellaria* trees have an ascending architecture, while *Parkia* branches are low and extend further laterally. In addition, Kater *et al.* (1992) observed that average panicle weights of sorghum and millet at one crown radius away from the

canopy boundary were lower on *Parkia* plots than on *Vitellaria* sites. This difference was dramatic with millet, suggesting that superficial rooting is more extensive in *P. biglobosa*, thus resulting in more intense competition with crops. While *V. paradoxa* hardly influenced cotton performance, cotton yields were negatively affected by *P. biglobosa*, mostly in the vicinity of its trunk. Because cotton did not suffer under cover of either species during establishment, Kater *et al.* (1992) concluded that the significant cotton loss under *P. biglobosa* was mostly due to tree/crop (possibly light) competition, and advised pruning experiments.

Crops are combined with some other tree species with little negative effect. The depressive effect of *Azadirachta indica* on sorghum is slight. In Burkina Faso, the sub-canopy sorghum yield was significantly lower by around 20 percent than at the edge of the crowns, but neither of these positions had significantly different yields from the open field (Tilander *et al.*, 1995). Similary, there was no significant difference in sorghum production at four distance under and away from *A. Indica* countries (Zoungrana *et al.*, 1993). In contrast to *V. paradoxa, P. biglobosa* and *A. indica*, *Hyphaene thebaica* had a significantly positive effect (2 to 2.5 times) on grain and straw yields of sub-canopy millet in Kareygorou and Say, southwestern Niger (Moussa, 1997). This is recognized by farmers and may be due to the palm's high and small crown and horizontally limited root system. Total dry matter production of millet and soil fertility were both even higher under *H. thebaica* than under *F. albida* trees in Kareygorou, though this was not true in Say (Moussa, 1997). *Borassus aethiopum* is also believed to associate with crops without intense competition (Cassou *et al.*, 1997).

Cardinal directions

Cardinal direction does not usually result in significant variation of overall production. Nevertheless, occasional studies report trends on the influence of orientation. In a system with successive harvests, Louppe (1993) observed that the first cotton harvest was larger in the open than under *Vitellaria* trees, but this pattern was reversed for the second harvest. The southern orientation was associated with higher yields in the first harvest and lower yields in the second. Average sorghum grain and biomass productivity on plots to the western side of *Vitellaria* trees was higher than on the eastern side in Mounzou, Mali, but not significantly so (Diakité, 1995). A similar pattern with statistically significant differences was observed for soil content of organic matter, calcium, magnesium and pH, as well as soil moisture in September. This result, due to dominant north-eastern winds influencing the direction of litterfall, confirmed the importance of increased soil fertility in improving yields in west-oriented plots.

Tree size

There are few data available on the influence of tree size on tree-crop interactions. Tree size is generally positively correlated with production gains under canopies of *F. albida* (Depommier, 1996a). The opposite may prevail with species with typical phenology, but the few reports do not provide a consensus opinion. Sorghum grain and biomass yields under *Vitellaria* trees with average crown diameters of 9.9 m were respectively 70 to 80 percent higher than under trees of larger diameter (15.4 m) (Diakité, 1995). This was attributed to the higher interception and evaporative demand of the larger canopy group. In a semi-arid (422 mm average rainfall) thornveld dominated by *Acacia karroo* trees ranging from seedlings to 3 m high mature trees, grass growth was more suppressed under trees taller than 2 m than under trees of 0.8 to 1.2 m height, possibly due to competition for water and

nutrients (Stuart-Hill and Tainton, 1989). In contrast, in Nigeria (with > 1 000 mm rainfall), herbaceous production was depressed under trees smaller than 3 m, whereas it was unaffected or positively influenced under trees higher than 7 m (Sanford *et al.*, 1982).

Parkland tree density and 'parkland effect'

One of the primary objectives of biophysical research on parklands should be to indicate the appropriate tree densities necessary for sustaining or improving parkland management. Unfortunately, available information on relationships between parkland density and crop production is very limited. Probably due to logistical difficulties and the only recent awareness that more intensive tree management should be pursued in traditional Sahelian agroforestry systems (ICRAF, 1995b), studies so far have been mostly limited to individual trees.

The relationship between herbaceous and woody plant productivity is complex and needs to be analysed within a given vegetation type, because it is influenced to a great extent by climatic and edaphic conditions (Breman and Kessler, 1995). Within a given vegetation type, increasing tree densities are usually associated with lower herb productivity. Both water and nutrient availability influence the competitive relationship between herbaceous plants and trees. Sites of lowest productivity can be expected to show the greatest rate of decline in herbage production with increasing tree density. Trees can also have a more intense negative effect on herbaceous biomass production in years of low rainfall.

The concept of 'critical canopy cover' seems highly relevant to the determination of optimum agroforestry parkland density from a biophysical point of view.

In semi-arid conditions, understorey herbaceous productivity is highest with low tree densities and decreases with increasing density. For instance, in Zimbabwe, the average yield of the herbaceous layer was 4.5 t/ha under open tree canopies compared with 2.8 t/ha in closed canopy sites and 3.0 t/ha in open grassland sites (Kennard and Walker, 1973). In areas afforested with *Albizzia lebbek*, *Prosopis cineraria*, *Tecomella undulata* and *Acacia senegal*, Ahuja *et al.* (1978) noted that herbage production was most depressed under *A. senegal* which had been planted in the highest densities. In savannas of northwestern Nigeria, Sanford *et al.* (1982) also found that higher production was achieved under a light canopy than in the open or under a dense canopy.

Other studies report an increase in understorey productivity with the artificial reduction of density or cover of woody plants (Breman and Kessler, 1995). These suggest the existence of a critical level below which herbage production is no longer increased with further cover reductions. Below the critical canopy cover, factors other than tree cover determine herbage production and/or beneficial effects associated with trees prevail over competitive ones. As canopy cover exceeds this critical level, herbage production decreases due to tree-herb competition. Breman and Kessler (1995) hypothesized that the critical canopy cover averages 15 percent in the Sahel and Sudan zones of West Africa for woody plant communities with two leaf layers.[4] This level would decrease going north as rainfall levels fall, and increase toward the south where annual rainfall is higher.

The concept of 'critical canopy cover' seems highly relevant to the study of agroforestry parklands (less so for the less competitive *F. albida*) and to the determination of optimum parkland densities from a biophysical point of view.

[4] The average number of leaf layers in natural woody plant communities ranges from 1.5 in the northern Sahel region to 4 in the southern Sudan region (see Breman and Kessler, 1995).

Farmers seemingly attempt to reach a certain range of densities perceived as 'ecologically-optimal' as they clear woodlands for agriculture. For instance, farmers reported clearing a relatively higher number of *Vitellaria* trees where their natural density was high (Boffa, 1995). *Vitellaria* stump counts in recently cleared fields showed that the number of eliminated trees per unit area was highly correlated with the original *Vitellaria* density (r^2=0.97). Farmers would spare a larger number of other useful species where *V. paradoxa* densities were originally low. They may also attempt to regenerate *F. albida* trees in fields of low stocking in order to reach a more productive density level, which is itself probably higher than the critical density level of *Vitellaria* parklands. Farmers are well aware that increasing tree density is desirable for crop production up to a certain level. In Holom, northern Cameroon, they reported that the biomass productivity of cotton increases to the detriment of cotton boll yields in the presence of too many *P. africana* trees (Bernard, 1996).

In northern Cameroon, a 32 percent increase in cotton production in plots located under a relatively dense *F. albida* parkland cover (37 trees/ha, 26 percent crown cover) was noted, compared with plots in an adjacent bare area (Libert and Eyog-Matig, 1996). This was unexpected because isolated trees tended to be associated with depressed cotton productivity. These results may suggest a positive 'parkland effect' linked to a spatial arrangement of scattered parkland trees, which would not exist in the presence of isolated individual trees and would consist in a synergetic increase in soil and air moisture, as well as less air circulation. Available evidence on this mechanism is presented in the next section. However, the observed difference could also be due to higher inherent soil fertility and better germination conditions of the area with trees (Geiger *et al.*, 1992).

It would appear that cereal crops would benefit from high *F. albida* densities, yet the productivity gain may decline as critical densities are reached. While high stocking levels have been reported in the Sahel, the relation to yields is rarely established. This parkland type illustrates the practical limits to the notion of critical canopy cover, as production objectives other than crop-oriented ones probably result in lower densities than those that maximum crop yields would dictate. Available data show that the highest yield increase is not necessarily positively related to density. In Watinoma, Burkina Faso, plots with the lowest *F. albida* density among three study sites located in a bottomland area showed the highest yield increase/tree density ratio. Tree size, pruning (or absence of), as well as site productivity also account for this result (Oliver *et al.*, 1996).

In *V. paradoxa* parklands of southern Burkina Faso on leached tropical ferruginous soils, the projected influence on sorghum productivity along canopy-wide transects between two trees was positive for densities of 12 and 30 trees/ha and negative for smaller trees at densities of 43 trees/ha (Boffa *et al.*, 1999). Although based on a limited sample size and a single experimental season, these results suggest that the maximum recommended density for medium-sized *Vitellaria* may lie somewhere between 30 and 43 trees/ha in this particular area.

An alternative approach was used by Bertelsen and Kaboré (1993). They argued that, in spite of the well-known yield variability in space and time, tree-crop interaction studies tended to focus on limited areas under and around trees rather than whole fields, and that yields were generally measured in single agricultural seasons. During interviews, farmers from two villages of Burkina Faso's Central Plateau gave expected yields for a total of 87 fields. Densities of trees, broken down into 'small' and 'large' classes, were determined from aerial photographs. The use of expected yields better reflected the long-term nature of tree density decisions. There was a strong positive relationship between densities (*V. paradoxa*

mostly) and yields suggesting that a 1 percent increase in tree density resulted in a crop yield improvement of 0.5 percent.

Such findings underline the important contribution of trees to overall soil productivity of agroforestry parklands in this region. It should be noted, however, that the biophysical parameters dealt with here are far from being the only ones influencing farmer decisions on optimal parkland densities. As illustrated in other chapters of this review, a range of cultural, socio-economic and institutional parameters, as well as objectives other than crop yields also come into play.

Influence of trees on microclimate

Light interception

Trees reduce the amount of sunlight reaching soils and crops through shading. The extent of reduction varies according to crown dimensions, tree phenology and leaf density (Breman and Kessler, 1995). Available evidence on reduction of solar irradiance by tree canopies is reported in Box 3.4.

Several studies in savannas suggest that tree shade increases understorey herbaceous productivity because of the reduction of temperature and evapotranspiration (Tiedemann and Klemmedson, 1977; Bernhard-Reversat, 1982). In Kenyan savannas, however, artificial shade increased herbaceous productivity in only

Box 3.4

How much do parkland tree canopies reduce sunlight intensity?

Solar irradiance was reduced by 45 to 65 percent under *Acacia tortilis* and *Adansonia digitata* (Belsky *et al.*, 1989). Only about 20 percent of total radiation reached the understorey of *A. tortilis* and *Balanites aegyptiaca* at midday in a Sahelian savanna (Akpo and Grouzis, 1996). Based on measurements of shade contours and corrections with photometer data, sunlight intensity was reduced to 45 percent under 10 to 13 m high *Vitellaria* trees and 20 percent under 14 m high *Parkia* trees, with successively less shading further away from the bole (Kessler, 1992). *Vitellaria* trees of 7 m height and 4.7 m crown diameter also decreased photosynthetically active radiation (PAR) directly under and outside crowns by 40 and 20 percent respectively (Boffa *et al.*, 1999). Under larger trees (average crown diameters of 8.4 to 11.2 m for *Vitellaria* and 9.5 to 17.1 m for *Parkia* trees), PAR was reduced by 75 percent on average (Jonsson, 1995).

In contrast to other parkland trees, *Faidherbia albida* generally loses its leaves shortly before the rains and remains leafless during the growing season. Light interception by this species is therefore generally considered to be small and does not affect crop production significantly. However, the extended leafing resulting from pruning (Box 3.2) suggests that crops are at least partially shaded. Shading by unpruned trees has not been quantified, but it appears to be slight because of the reduced crown and its partial recovery and densification during the initial three to four months of cropping (Depommier, 1998). It may have a positive effect on crop establishment, but a negative one at the grain filling stage when high insolation is required for cereals.

When trees are defoliated, the reduction of solar irradiance by branches, especially low ones (Poschen, 1986), may be important. Maximum radiation around midday in May under a nearly leafless *F. albida* was about half that in the open and shade had a substantial impact on soil temperature (van den Beldt and Williams, 1992). Radiation was also reduced by 30 to 40 percent under leafless *Acacia tortilis* and *Adansonia digitata* during the dry season (Belsky *et al.*, 1989).

one open site (Belsky, 1994). This was attributed to the physiological adaptation to shade of particular plant species, consisting in their capacity to reduce their stomatal apertures and conserve moisture at low light levels (Amundson *et al.*, 1995). Belsky (1994) could not establish clearly whether microclimate or nutrient enrichment was responsible for increased productivity under trees. But if stomatal conductance is primarily responsible for the increase in productivity in open sites, one would assume that agricultural crops, especially C_4 crops which are generally adapted to full light conditions and sown uniformly under and outside parkland tree cover, could not benefit significantly from conditions associated with reduced light intensity. In turn, higher soil nutrient levels may be the dominant advantage of parkland trees for crop production.

In contrast to herbaceous productivity in savannas, substantial evidence shows that light interception by tree canopies is associated with decline in C_4 crop productivity. Reduction of photosynthetically active radiation (PAR) generally results in a decline of C_4 grain productivity, as shown in a standard light curve for maize (ICRAF, 1993). Sorghum yield decline from a distance of two crown radii towards the bole was strongly correlated with a consistent decrease in average light intensity estimates (Kessler, 1992). Boffa *et al.* (1999) found a significant decrease in sorghum yields with increasing canopy size in plots of fixed location bordering the canopy edge. Light was a determining factor of grain yield variation in plots located under tree crowns. Shade of *F. albida* does not appear to have a significant impact on cereal yields, but this would need to be precisely tested in the case of intensely pruned trees. However, Poschen (1986) found the shade from branches significant and recommended that *F. albida* branches up to 4 m be pruned in order to minimize light competition with crops.

Smaller *V. paradoxa* trees were also associated with less yield depression (Kessler, 1992) or higher production (Diakité, 1995) than larger ones. Kessler recorded a greater depressive effect for both *Vitellaria* and *Parkia* trees than Maïga (1996) or Kapp (1987), and attributed this to the larger tree size (10 to 13 m) in Oula. Likewise, a smaller yield decrease of 10 percent was found in *Vitellaria* parklands with average tree height of 7 m (Boffa *et al.*, 1999). This was not the case in Saponé, Burkina Faso, where neither the percentage of light reduction nor crop yields changed markedly according to tree size under small and large *Vitellaria* and *Parkia* trees (Jonsson, 1995). Indeed, millet biomass production was found to be higher under a large *Parkia* tree than under a small one or under *Vitellaria* trees or in controls, maybe due to a relatively higher nitrogen content. Despite this isolated case (presented in more detail below), one may conclude that reduction in light intensity varies according to tree shape and size and generally contributes to yield depression of C_4 grain crops in the proximity of these parkland species. In contrast, C_3 crops are adapted to lower light intensities and their yield may be less depressed by partial shade.

Temperature

Temperatures are lower under tree canopies due to shading. In semi-arid Kenya, soil temperatures 5 cm below the surface were at least 5-9°C lower under trees than in the open grassland, both at the beginning of the growing season and when grass cover was at a maximum. The difference between locations decreased with soil depth (Belsky *et al.*, 1989). Soil temperature was also substantially lower under *Vitellaria* and *Parkia* trees than in the open (Jonsson, 1995). An almost leafless crown of *F. albida* resulted in a soil temperature decrease of up to 10°C at 2 cm depth (van den Beldt and Williams, 1992). In northern Senegal, air temperatures under and outside tree canopies differed by 6°C at maximum temperatures (Akpo

Although crop establishment and growth are impeded by extreme heat, there is no conclusive evidence of shade being responsible for better yields under* Faidherbia *trees, than in the open.

and Grouzis, 1996). In addition, the variation of soil temperatures at 10 cm depth during the day was lower under canopies (3°C) than in full sunlight (9°C). Maximum and minimum air temperatures are moderated by tree crowns because of reduced solar radiation during daytime and reduced reflection of infrared radiation at night (Dancette and Poulain, 1969).

Temperature reduction has been held responsible for enhanced yields under *Faidherbia* crowns. There is some evidence that extreme heat negatively affects crop establishment and subsequent growth (Ong and Monteith, 1985; Peacock *et al.*, 1990; McIntyre *et al.*, 1993). Using vertical artificial screens, van den Beldt and Williams (1992) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) showed that the effect of shade on soil temperatures contributed to better millet growth during seedling establishment. They argue that root damage due to high temperature rather than water deficits caused differences in millet performance, and that crops would not be able to take advantage of the greater soil fertility around *F. albida* trees without the moderated temperature associated with them. However, this study was conducted on-station where soils are possibly more fertile than at on-farm sites. Furthermore, it was done in May when temperatures are very high, whereas millet is normally sown in late June or early July in this area, and it was conducted for only six weeks, thus not encountering nutrient constraints.

A subsequent on-farm experiment in N'dounga, Niger, attempted to quantify the effect of soil fertility independent of other *F. albida* microclimate-related effects, with treatments including single and combined doses of nitrogen and phosphorus fertilizers (ICRAF, 1996). No effect of tree canopy or fertilizer treatments on seedling survival was visible 25 days after sowing, and the difference between *F. albida* and open sites in millet canopy temperature was only 1.8°C. The *F. albida* effect was made up of the effects of nitrogen and phosphorus which were the most limiting resources for millet growth in this study, while shade had no direct influence. (Nitrogen fertilization cancelled the difference between yields in the crown zone and the open.) Thus, temperature moderation by *F. albida* may not influence cereal stand establishment as much as was previously believed.

The potential positive effect of temperature reduction in species such as *V. paradoxa* and *P. biglobosa* is usually not visible, due to reduced yields blamed on PAR reduction and on increased humidity resulting from shade. Surprisingly, however, in Saponé, Burkina Faso, millet productivity under both canopies was relatively high (highly variable and not significantly different) compared with the open in a year of far higher rainfall than average, in spite of a 65-75 percent reduction of PAR (Jonsson, 1995). Jonsson thus assumed that the positive effects of soil temperature reduction due to tree cover offset the negative impact of shade on photosynthesis. She supported her findings by suggesting, first, that supra-optimal soil temperatures impede seed germination and seedling establishment (Peacock *et al.*, 1993). There is also evidence that they significantly constrain subsequent growth and development (McIntyre *et al.*, 1993). Secondly, lower sub-canopy temperatures caused a 15-day extension in crop duration, which is advantageous in years of extended rainfall. In turn, a 15-day reduction in crop duration would generate a 15 to 20 percent production decline (Squire, 1990, cited in Jonsson, 1995). The effect of high humidity on crop failure due to pest attacks, which was found in other studies, was not reported. Given the opposite results found in other studies on the same tree species, Jonsson suggested that the overall impact of microclimate moderation on crop production might depend on annual rainfall conditions for reasons not yet fully understood.

Diakité's (1995) results in the western part of the Middle Bani area of Mali also deviate from the yield depression generally observed under *Vitellaria* crowns. However, the

overall average yield increase of 26 percent (Table 3.3) under and away from tree canopies hides substantial differences related to tree size, with sub-canopy yields in the larger tree size group (15.4 m diameter) appearing to be lower than yields in the open (despite the opposite pattern for the whole sample). This suggests that the reduction in solar radiation under larger canopies does indeed have a negative effect on sorghum production. Nevertheless, tree size in the smaller group is similar to that in other studies (Kessler, 1992; Kater *et al.*, 1992) but gives opposite results. The dramatic increase in sorghum grain (80 percent) and straw yields (70 percent) in the vicinity of smaller trees (9.9 m in crown diameter) compared with plots around trees of larger crown diameter (15.4 m) in a year of low rainfall suggests a significant influence of the microclimate. Diakité attributed it to the higher interception and evaporative demand of the larger canopy size group.

Evapotranspiration and soil moisture

A higher topsoil moisture under woody canopies than in treeless sites appears to be a common pattern during the rainy season and some time afterwards. For instance, soil moisture at 0-10 cm depth during the end of the rainy season was twice as high under *F. albida* canopies as in the open (1.4 versus 0.7 percent), probably due to lower evapotranspiration (Charreau and Vidal, 1965). A similar pattern was observed under pruned *Faidherbia* trees in Burkina Faso in the early and late season (Depommier, 1996a). Dancette and Poulain (1969) also found that soil moisture was higher under *F. albida* trees than in open controls in the top 120 cm, but was lower in deeper horizons (down to 4 m) due to water absorption by deep tree roots. (During the rainy season, water reaches deeper horizons under trees than in the open because of better infiltration (stemflow, soil texture) and reduced evapotranspiration.) Rhoades (1995) recorded increased soil water in the top 15 cm of soil beneath *F. albida* canopies in Malawi. The increase over open sites rose from 4 percent at the end of the dry season to 53 percent at the end of the cropping season.

Soil moisture in unspecified soil depth and period was significantly lower (4.7 versus 9.3 percent) in the open than under both *Hyphaene thebaica* and *F. albida* in Kareygorou and Say, Niger (Moussa, 1997). There was also a decrease in topsoil moisture with increasing distance from *V. paradoxa* trees at three dates toward the latter part of the rainy season in southern Burkina Faso (Boffa *et al.*, 1999). In northern Cameroon, soil water available to cotton, as calculated from soil humidity measured by probes, seemed little affected by *F. albida* trees in the 0-80 cm soil horizon in which cotton roots were concentrated and where hardly any tree roots were detected. Moisture available to plants appeared higher under trees at the beginning and end of the season than in open field controls, but this difference was significant only for one site (Libert and Eyog-Matig, 1996).

The higher soil moisture in tree sites described above is generally assumed to be due to reduced soil evaporation and plant transpiration caused by shading and the resulting lower temperatures (Belsky *et al.*, 1989). To illustrate, in a *F. albida* stand of 25-30 trees/ha, potential evapotranspiration was 50 percent lower during the dry season when trees were in full foliage and 10 percent lower during the rainy season than in a bare field (Schoch, 1966). In Bambey, Senegal, evapotranspiration was reduced from 2 200 mm in an open degraded field to 1 850 mm in *F. albida* windbreaks and 1 520 mm in a location sheltered with constructions and neem or *Prosopis* hedges. Over a period of two years, the lowest reduction in a field with scattered *Faidherbia* trees was 5 percent compared with the open field (Dancette and Niang, 1979). During two short periods in July in a season of exceptionally high rainfall in Burkina Faso, evaporation under *Vitellaria* and *Parkia* trees was 22 percent lower

Box 3.5
Wind speed reduction in agroforestry parklands

The role of trees in wind protection has been studied mainly in relation to linear shelterbelts. In a state-of-the-art paper on the effects of parklands on microclimate, Stigter *et al.* (1996) presented recent insights on air movement around shelterbelts and in canopies, and noted the lack of understanding of air movement and the lack of research on scattered trees in typical parkland situations.

Agroforestry parklands appear to reduce wind velocity in certain conditions. In Burkina Faso, Jonsson (1995) measured a significant difference in wind speed under small and large *Vitellaria* and *Parkia* trees compared with the open. Wind velocity reduction was held responsible for a 15-20 percent decrease in overall water consumption in *Faidherbia albida* stands as compared with bare land (Dancette, 1966). In Tanzania, wind speed patterns were investigated along lines parallel to wind flow into a woodland made up of scattered trees, mostly *Acacia tortilis* and a few other species such as *Acacia mbuluensis*, *Commiphora schimpere* and *Balanites glabra* of 5.5 m average height (Kainkwa and Stigter, 1994). Wind speeds decreased approximately linearly into the woodland until they became almost constant (saturation reduction). The minimum length of woodland (estimated density of 120 trees/ha) for a maximum of 50 percent wind reduction was about 110 m at 1.0 m height and about 80 m at 2.5 m height. Tunnelling effects under tree canopies seem to cause lower wind speed reductions at 1.0 m than at 2.5 m. With a lower tree density of about 60 trees/ha, significant wind reduction was found only at 2.5 m. Therefore, scattered trees in parklands, much like shelterbelts, can reduce wind speed significantly at given densities (especially 120-150 trees/ha). Furthermore, once the saturation point in wind reduction is reached, small gaps in tree cover are likely to have little influence because air affecting the woodland decouples from the main winds above the system. Likewise, wind reduction will be more pronounced in large expanses than in isolated patches of parklands. Vertical and horizontal tree biomass distribution (including stem height) and species composition influence wind reduction patterns, as demonstrated around single trees (Gross, 1987; Stigter *et al.*, 1996).

Taking into account the paucity of data available, it nevertheless seems that the minimum densities at which sufficient wind reduction occurs are higher than most parkland densities observed in the region. Lower densities of higher and larger trees, as often found in Sahelian parklands, may be similarly effective, however. Therefore, further studies focusing on parkland examples, and aimed at identifying optimum characteristics (canopy management, tree density, size and species combinations), are desirable.

than in the open (Jonsson, 1995). Traditional rice fields located in bottomlands or on slopes, and surrounded by trees, showed a 40 percent reduction in evaporation compared with a modern treeless rice-growing area in Djibélor, Senegal (Niang, 1998).

Mechanisms involved in evaporation are similar on plant leaves and on a water surface. Evaporation is proportional to wind speed and the vapour pressure gradient between the evaporating surface and air. Wind reduction by parkland trees (Box 3.5), therefore also contributes to decreased evapotranspiration, even though few data are available to prove this relationship. The additional link between wind reduction at the scale of a spatially defined population of parkland trees, rather than at the scale of an individual tree, and crop productivity, could be the primary cause of the 'parkland effect' which was discussed earlier.

Seasonal variations in soil moisture

Differences in soil humidity recorded under trees and in the open vary according to season. At the onset of rains, especially light ones, sub-canopy soil moisture is usually lower under savanna trees than in the open because of at least partial canopy interception and subsequent evaporation (Box 3.6). A lower sub-canopy

Box 3.6
Rainfall interception by parkland trees

The amount of rainfall intercepted by trees varies according to rainfall intensity. In Senegal, a lower rainfall was recorded under *Faidherbia albida* trees during light rains because of canopy interception and subsequent evaporation, while there was a sub-canopy rainfall surplus during heavy rain storms to the detriment of the area leeward of the trees. Over a month and a half of rainfall measurements, the balance was a 9 percent surplus under *F. albida* trees compared with the open, but this did not include stemflow (Dancette and Poulain, 1969). In Cameroon, there was 9 and 6 percent less rainfall in pluviometers located under and at the edge of *Faidherbia* canopies, respectively, than in open controls over the whole season (Libert and Eyog-Matig, 1996). The fact that only one (unspecified) transect orientation per sample tree was monitored may explain the difference between these and the Senegal findings. *Cordyla pinnata* canopies in Senegal intercepted 22 percent of gross rainfall, and interception declined with increasing gross precipitation. The storage capacity of *C. pinnata* canopies was 5 mm (Samba, 1997).

moisture may continue during the first part of the rainy season in northern and drier latitudes, as the tree and herb layers together may utilize more water than a sole grass or crop component. Effective evapotranspiration of an *Acacia tortilis* and *Balanites aegyptiaca* grassland community measured over a soil depth of 475 cm was higher than for a solely grassland area monitored in the top 60 cm (Nizinski and Grouzis, 1991).

Later during the rainy season, tree sites tend to be more humid than open locations, because of reduced soil evaporation and plant transpiration due to lower temperatures and reduced radiant energy (Akpo, 1993). The pattern of higher moisture under trees during the middle of the season does not always apply. The distance from *Vitellaria* trees did not affect soil water content in Mounzou, Mali (Diakité, 1995). Under *F. albida* in Burkina Faso, differences in soil moisture content subsided in the mid-season as rainfall was abundant and leafless trees caused little shade and rainfall interception. Topography may also influence the tree-related variability of moisture content. Thus no difference was noted in lower toposequence positions, which are rapidly saturated with rain water, during the agricultural season (Depommier, 1996a). The higher plant productivity, due to better soil fertility under tree crowns in savannas, and the associated rise in evapotranspiration may reduce the sub-canopy moisture surplus and lead to similar moisture content in surface soils (Belsky *et al.*, 1989). As the dry season proceeds the topsoil gradually dries out uniformly.

Soil moisture variations according to tree size

One would expect greater declines in temperature under the total area of large, dense and spreading canopies than under small, light and erect tree crowns. These would also imply lower soil evaporation and crop transpiration as well as increased soil humidity. In Malawi, soil moisture was not higher under small *F. albida* trees than in the open, as their leafless canopies did not create enough shade to reduce evapotranspiration. However, surface soil moisture was consistently higher under large crowns throughout the growing season (Rhoades, 1995). Similar findings result from comparing trees with different crown sizes due to pruning. In the Bulkiemdé parklands in Burkina Faso, for example, Zoungrana *et al.* (1993) measured a more rapid decrease (5 versus 8.6 percent) and lower content of soil moisture (10 versus 12 percent) under *Azadirachta indica* trees (crown radius £3 m) pruned two years earlier than under unpruned ones (radius ≥ 3 m) over a 12-day period during which the understorey crop was in the flowering stage (statistical

significance was not tested). It should also be noted that differing tree shape affects the way species influence microclimate and soil water. In northern Senegal, the higher evapotranspiration in *A. tortilis* than *B. aegyptiaca* stands was attributed either to the higher interception of the former's spreading crown or to its higher absorption/transpiration (Nizinski and Grouzis, 1991). Additional research into water use of parkland trees in managed conditions is desirable.

In contrast to the above, larger canopies may also reduce soil moisture by generating more evapotranspiration due to their more extensive exchange surface between foliage and air. This is especially true towards the late part of the rainy season when rainfall events become less intense and frequent and temperature rises. In Mounzou, Mali, for example, Diakité (1995) reported that soil moisture under small *V. paradoxa* canopies (9.9 m diameter) was significantly higher than under larger crowns (15.4 m diameter) in September (0.144 versus 0.131 g water/g of dry soil) and October (0.0824 versus 0.0644 g).

The apparently conflicting results presented here may be reconciled by acknowledging that the process of reduced crop transpiration and soil evaporation under larger crowns may be generally valid, while the mechanism of greater evapotranspiration in canopies may apply primarily in the latter part of the rainy season and be felt more intensely under large tree crowns. As microenvironmental benefits of trees are conferred to the system in the long term, a finer analysis along a gradient of tree size would be useful to indicate when these benefits may arise.

Air humidity

Air humidity, which results from lower air temperatures and higher top soil moisture under trees, is usually higher under tree canopies than in the open (Breman and Kessler, 1995). Relative humidity in July was 59 percent under *F. albida* trees and 51 percent away from them in Senegal (Dancette and Poulain, 1969).

Apart from intercepting solar radiation, canopies may also reduce crop viability through increased humidity. Kater *et al.* (1992) observed that cereal crop survival was lower in the proximity of trees than in the open and attributed this to higher air and topsoil humidity favouring fungal infection. Crop establishment failure made a relatively greater contribution to the decline in overall grain productivity for sorghum and millet, under both *Vitellaria* and *Parkia* trees, than for cotton under *P. biglobosa*. Rather than pruning treatments, Kater and colleagues recommended crop mixtures adapted to higher moisture conditions under these trees. Only 8 percent of plants sowed under *V. paradoxa* failed to reach maturity in southern Burkina Faso (Boffa *et al.*, 1999). Kessler (1992) reported that crop maturity under trees was retarded and that about 5 percent of sorghum panicles under trees were infected with a virus, *Spacelotheca sorghi*. Accumulated water was observed in flag leaves of sorghum long after rainy events under *Vitellaria* canopies, suggesting high air humidity, and possibly increased susceptibility to fungal attack (Boffa *et al.*, 1999).

Influence of trees on species composition

There are few references to understorey species composition in agroforestry parklands because wild herbaceous species are replaced by agricultural species. Nevertheless, research in Watinoma and Dossi, Burkina Faso, has shown that *F. albida* significantly reduces the density of the plant parasite, *Striga hermontica*, which causes considerable yield loss in degraded soils. The extension of shade

under pruned trees during the agricultural season seems to be detrimental to the species which requires high solar intensity for its development. Besides higher weed growth under trees, the floristic diversity in weeded plants growing under *F. albida* crowns tended to be lower than in the open in Cameroon (Libert and Eyog-Matig, 1996). More palatable and shade-loving grasses (*Panicum maximum* and *Brachiaria spp.*) were dominant under *P. biglobosa* canopies, while less palatable *Andropogon* and *Imperata* spp. prevailed outside canopies (Sabiiti and Cobbina, 1992).

Influence of trees on phenology

Vegetative development of herbaceous plants is generally longer in plants growing under woody canopies (Weltzin and Coughenour, 1990). Weed growth tended to start earlier under *F. albida* canopies than in open controls (Libert and Eyog-Matig, 1996). Duration of the vegetative plant development was longer in cotton in the proximity of *F. albida* (Libert and Eyog-Matig, 1996), as well as in sorghum under *Vitellaria* and *Parkia* canopies (Kessler, 1992).

In the *Acacia caven*-based silvipastoral system, the vegetative development cycle of plants growing in the shade of these trees was 25 to 35 days longer than in the open (Ovalle and Avendano, 1987; Akpo and Grouzis, 1996). The proportion of species displaying a short vegetative cycle was also higher in stands where tree cover had been eliminated than in stands with an *A. caven* cover of 80 percent. Plant emergence took place two weeks earlier in tree-adapted species than in plants found outside, while flowering stages started earlier, lasted a shorter time and had a lower success rate in the open than under tree canopies (Akpo and Grouzis, 1993).

Summary

The interactions between different biophysical factors in determining the productivity and sustainability of parkland systems are very complex. An overall understanding is still lacking because most studies to date have focused on the various interactions in isolation and have also extrapolated from experiments on individual trees to the parkland level.

The effect of parklands on soil fertility is of particular interest. Soils under tree canopies, in both savannas and parklands, generally display a higher fertility than those in the open. This pattern of higher fertility under tree crowns is usually characterized by a gradual decline with distance away from the trunk as well as with soil depth. Nutrient enrichment by trees also appears to increase with tree size. Studies of the relationship between soil fertility and tree density have so far been inconclusive. Comparative increases in nutrient content are highly significant under *Faidherbia albida* trees, and less remarkable though still common in other parkland species. Cardinal orientation may also affect nutrient concentrations in the subcanopy zone, with differential organic matter accumulation due to wind or asymmetrical crowns.

Several mechanisms may account for the increased fertility under trees. Nutrients are returned to the soil through deposition of litter, root decay and exudation, as well as the leaching of tree nutrients in rainfall. Biological processes appear to be particularly important with tree sites being characterized by higher macrofaunal and microbial activity, as well as higher mineralization rates, lower bulk density and better water infiltration rates than treeless locations. A few studies report that subcanopy soils are associated with a larger proportion of fine-textured elements than in the open, which may be due to limited soil erosion, increased termite activity or pre-existing soil differences. Interception of wind-blown material may be another important yet seldom measured factor.

Nitrogen fixation increases soil nitrogen content but appears relatively limited in adult tree populations and constrained by availability of phosphorus in the Sahel. Nutrients are concentrated under trees by livestock looking for shade and fodder, as well as by wild fauna. The few quantified measures indicate that livestock droppings probably have a significant responsibility in enhanced crop performance under trees in *F. albida* parklands. Fertility distinctions between tree sites and interspaces may also be related to pre-existing fertility or different soil management practices.

Where trees are associated with increased soil fertility, the question remains as to whether this is due simply to a redistribution of nutrients or whether trees engender a process of nutrient enrichment. Trees can contribute to nutrient redistribution by lateral root uptake and animal and atmospheric deposition. Alternatively, they may increase nutrient availability in the system by reducing losses through leaching and soil erosion and by adding nutrients through N-fixation, with nutrients absorbed by deep roots, and mycorrhizal infection. Although these enrichment processes have been documented they may not be widespread. Thus deep rooting is frequently limited by root barriers in semi-arid West Africa and its nutrient contribution is low, due to the low nutrient content of deep soil layers.

The effect of parkland trees on soil fertility is just one component of their influence on crop productivity. The vertical distribution of tree and crop roots suggests that competition and facilitation both occur in agroforestry parkland systems. Competition patterns are linked to tree root distribution, which often extends far

beyond the crown area in arid conditions, while it is confined within or close to the crown area in subhumid zones. Available data suggest that *F. albida*'s underground competition with crops is small because of its deep taproot and reverse foliation (although pruning may cause it to refoliate during the rainy season). In contrast, competition for nutrients may be higher for parkland tree species with a similar phenology to crops. Even so, its depressive influence may be less significant than that of shade in these species.

In cereals, *F. albida* is responsible for a substantial increase of grain yields under its canopy, often equivalent to the yield improvements expected from fertilizer additions. The *F. albida* effect is more pronounced on soils of low fertility, in years of below-average rainfall, and in the absence of fertilizers. It is also positively related to tree diameter, but can be obscured by pruning. The distribution of yields within the canopy zone usually decreases regularly from the bole to the edge of the crown or peaks within the second half of this zone. In the case of *Vitellaria paradoxa* and *Parkia biglobosa*, crop performance may be significantly reduced, but there is also some evidence to the contrary. Neem (*Azadirachta indica)* depresses crop yields to a lesser extent while *Hyphaene thebaica* stimulates cereal crops, probably because of its high, small crown and limited horizontal root extension.

With the possible exception of *Prosopis africana*, yield depression is more pronounced on soils of low fertility. C_3 crops are generally less affected by trees than C_4 plants. Tree species with contrasting branch architecture and rooting patterns, as illustrated by *P. biglobosa* and *V. paradoxa*, differ in underground and above-ground competition patterns with crops, making a reduction of crown area and/or limiting root competition desirable. Tree size is generally positively correlated with production gains under canopies of *F. albida* but there is no consensus on its effect in species with typical phenology.

The effect of trees on crop production may be accounted for in part by changes in microclimate. Trees generally intercept 20 to 80 percent of incident solar radiation depending on size and species. Even when leafless, savanna and parkland canopies are associated with lower temperatures (and evapotranspiration) than in the open because of reduced solar radiation during the day and reduced reflection of infrared rediation at night. Studies in savannas suggest that tree shade thus induces higher understorey productivity. However, although crop establishment and growth are impeded by extreme heat, there is no conclusive evidence of shade being responsible for better yields under *Faidherbia* trees, than in the open. The positive temperature effect of shade in species such as *V. paradoxa* and *P. biglobosa* is usually not apparent in the overall reduced yields, but has been said to offset the decline in photosynthesis in a year of high rainfall in Burkina Faso. The magnitude of the negative shade effect rises with increasing canopy size and is more prevalent with C_4 than C_3 crops. The specific contribution of nutrient enrichment and microclimate will need to be clarified through experiments with artificial shade, fertilizers and their combination under and away from parkland trees and over several years.

Moisture in the topsoil is generally higher under woody canopies during the rainy season because of reduced soil evaporation and plant transpiration as a result of shading and lower temperatures. This pattern may not apply at the beginning of the season, because of interception of rainwater, as well as later due to higher evapotranspiration of increased understorey plant biomass, and/or absence of leaves in pruned *Faidherbia* trees. Wind speed reduction probably contributes to reduced evapotranspiration and crop productivity, but this link has not yet been established. The higher air humidity under *Vitellaria* and *Parkia* canopies appears

to be conducive to pest attacks and crop failure, while *F. albida* shade is associated with higher weed growth, lower weed diversity and a significantly lower density of the plant parasite *Striga hermontica* than in the open. The vegetative development of crops generally takes longer under than outside of woody canopies.

Relationships between parkland density and crop production are complex and available information is limited because of logistical difficulties. A concept of critical canopy cover has been proposed. Below this critical level, herbage production is no longer increased with further tree cover reductions while, above this level, herbage production decreases due to tree-herb competition. There may also be a positive 'parkland effect' on crop production linked to the spatial arrangement of scattered parkland trees, which would not exist in the presence of isolated individual trees, consisting of a synergetic increase in soil and air moisture, as well as less air circulation. However, no scientific evidence of this effect has yet been provided.

IMPROVED PARKLAND MANAGEMENT

CHAPTER IV

Approaches to halt and reverse land degradation and desertification in the Sahel in the 1970s and early 1980s focused primarily on externally driven forest protection and tree-planting. Indigenous forest management systems were generally assumed to be destructive. As governments' forest management approaches have become more integrated, however, and increasingly elicit local participation, the variety and value of indigenous forest management systems have gradually been recognized. Knowledge of the techniques used, and the scale, purpose, and impact of traditional management practices in the Sahel is still limited (Savenije, 1993, cited in Breman and Kessler, 1995), yet indigenous knowledge in this field is a necessary point of departure for the development of improved practices (A.S. Ouédraogo, 1995). This chapter reviews existing management practices in agroforestry parkland systems and the available research findings on promising techniques. These technologies aim at improving parkland tree density and the production of the tree component and/or crop production.

Parkland management practices

Assisted tree regeneration

Given the variable results and high cost of projects focusing on tree planting, there is increased interest in the protection and stimulation of natural tree regeneration where mother trees are available (Taylor and Rands, 1991; Montagne, 1996; Sumberg, 1990, cited in van den Beldt, 1996; Joet *et al.*, 1998). The objective of assisted regeneration is to encourage farmers to identify, protect and stimulate the growth of naturally regenerating shrubs and trees in their fields. Young woody plants are staked (often with painted stakes so that they are easily visible) and protected from grazing, tillage and fire. If the objective is parkland formation or enrichment, woody plants will need to be protected for many years, while more limited protection is sufficient if they are being regenerated to satisfy fuel and construction wood needs.

In comparison to tree planting, for which returns may often require five to ten years, natural regeneration in dry zones of the Sahel has the advantage of providing relatively short-term (two to three years) benefits in the form of wood from pruning/thinning and an environment which is better able to sustain crop production. It is also technically easy to apply and reproduce, is relatively low-cost and requires little community organization (Taylor and Rands, 1991). Where these short-term benefits are reported, north of Maradi in central Niger, as well as further south around Mayahi, most species resprout vigorously, show rapid growth and can thus have productive and environmental functions within a few years (Joet *et al.*, 1998). The type and quantity of wood harvested are also sufficient to meet household needs for fuel and construction. However, in neither of these two cases do regeneration techniques necessarily lead to the establishment of parklands. Project personnel observe that they are practised in drier and more marginal areas than those where parklands are generally found, or using species that are not traditionally considered as parkland species, or because the primary purpose in areas of high population density is wood and fodder production rather than intercropping.

Fig. 4.1 ***Vitellaria paradoxa*** **subsp.** ***nilotica*** **regeneration being actively protected in a house field, Adwari, Uganda** ***J.-M Boffa***

The benefits of natural regeneration are clear. As a result of the 1981-1985 Gao Project in Dosso, Niger, *Faidherbia albida* densities in fields have dramatically increased from 4.9 trees/ha in 1981 to 29 trees/ha in 1992 (Montagne, 1996). As evidenced by the presence of small saplings in fields in 1992, farmers have now adopted the technique and extended the protection of regeneration to other tree species as well. The technique is also applied in other areas of Niger. As a result of improved clearing methods, densities of up to 100 shoots/ha of species including *Guiera senegalensis, Combretum glutinosum* and *Piliostigma reticulata* are maintained in the fields of several hundreds of villages around Mayahi, Niger (Joet *et al.*, 1998). Exposure to extension work by technical services and development projects has been one of the factors determining village adoption of the technology. Protection of shrubs such as *Guiera senegalensis* has also been encouraged further south in Burkina Faso, on degraded land where tree cover is particularly low (Lowenberg-Deboer *et al.*, 1994).

In Senegal, farmers had several suggestions for promoting farmer motivation to increase *F. albida* regeneration. Farmers protecting regeneration could be exempted from all or part of the rural tax. Peanut seeds could be offered in exchange for tree regeneration and protection. Contests with food or cash prizes could be organized within or between villages to reward farmers with the highest rates of regeneration. Finally, one or two village farmers trained in silvicultural techniques could serve as local forestry resource people (Seyler, 1993).

Farmers plant trees usually confined to the proximity of homes where tenure is more secure, soils are better fertilized and seedlings are protected from browsing, drought and fire.

Planting of parkland species

Traditionally, parkland species which easily regenerate naturally are not planted. For instance, in Dori, Burkina Faso, 90 percent of all dominant parkland trees are regenerated naturally rather than planted (ICRAF, 1996). However, the importance of planting as a technique for parkland establishment and regeneration depends on parkland type. *Borassus aethiopum* parklands such as those of Wolokonto, in southwestern Burkina Faso, are believed to have been planted originally, even though the species is locally present in natural stands. Planting is still actively practised every two or three years in order to replace trees which do not survive tapping (Niang, 1975), and even results in increased density and spatial extension of parklands. Fallen *Borassus* fruits are gathered and heaped in fields, and sprouted seeds are then planted, often in lines for easier mechanized cultivation and for plot delineation (Cassou *et al.*, 1997). On the Seno plain of Dogon country in Mali, *Adansonia digitata* trees are planted in compounds and nurtured before they are transplanted along the edge of cultivated fields (Sidibé *et al.*, 1996).

In addition, numerous references indicate that farmers actively regenerate tree species when the benefits of their investment are guaranteed, as a response to land degradation and the rarefaction of trees in their agricultural landscape, or because of the subsistence and economic value they provide. Deliberate tree planting takes place mostly in the vicinity of family compounds, where browsing of animals, fire and harvesting can be controlled and where the use of household refuse, animal manure, and plant residues contributes to higher soil fertility than in distant fields. In many cases farmers prefer to plant exotic tree species because of social customs and the long time indigenous species take to reach maturity and yield expected benefits. Generally they prefer to rely on wild trees to meet their local species' needs, although there are local variations.

In Petit Samba, Burkina Faso, all male interviewees declared that they planted exotic tree species, while only a few transplanted indigenous *Vitellaria paradoxa*, *A. digitata* and *Parkia biglobosa* wildings from under mother trees to compound

Fig. 4.2 Expansion of *Borassus aethiopum* parkland through active regeneration (foreground)
R. Faidutti

areas where they could be watered and protected (Gijsbers *et al.*, 1994). Around 85 percent of compounds and 16 percent of (non-compound) fields surveyed in 21 villages of central Mali had planted trees, while the non-compound figure was 38 percent in six villages of the Bandiagara area. In compounds, the primary species was the exotic *Azadirachta indica* (neem) while farmers planted (or transplanted) *B. aethiopum, A. digitata, F. albida* and neem in fields (McLain, 1991a). In Houet, Burkina Faso, and Benin, *P. biglobosa* is sometimes sown at the same time as crops (A.S. Ouédraogo, 1995). In Senegal, farmers often plant neem, mango and *B. aethiopum* on field borders or in fields next to family compounds (Seyler, 1993). Kessler and Boni (1991) report that farmers plant several tree species in compound fields in Burkina Faso, for example *P. biglobosa* in Sissili, *A. digitata* in Kossi, *B. aethiopum* in Comoė and *H. thebaica* in Seno. *Vitellaria paradoxa* is virtually never planted except in rare cases such as at Kokologho, Burkina Faso. The practice of growing neem to produce roofing poles has become widely established in northern Ghana over the last 20 years on farmer initiative (Norton, 1987, in Shepherd, 1992).

In Nigeria, neem and *Eucalyptus* are planted in parklands of Katsina State (Otegbeye and Olukosi, 1993). In Sotoko, planting of *P. biglobosa* was practised by 30 percent of farmers interviewed (Popoola and Maisanu, 1995). In the densely populated Close-Settled Zone of Kano, 71 percent of respondents of all ages reported planting trees in farmed parklands. Species included mango, *P. biglobosa, Ficus thonningii,* neem, *Ceiba pentandra* and *F. albida* in descending order of importance (Cline-Cole *et al.*, 1990). Montagne (1986) presents numerous local instances of nursery creation, multi-purpose tree plantations, fallow enrichment by direct seeding and marketing of seedlings in Niger as a result of individual initiatives. The establishment of fruit species in groves is also often reported. In Wolokonto, southwestern Burkina Faso, mango, citrus, guava and cashew trees have traditionally been planted in small clumps next to farmer compounds, and this is now also practised further out in parklands (Cassou *et al.*, 1997).

In response to drought and the decline of aquifer levels, farmers in the Peanut Basin of Senegal have tested a method for successfully establishing mango trees on Dek Dior soils. They introduce a mango seedling in a planting hole where a young *B. aethiopum* individual is already growing. Thus, the water that the latter species is able to extract at certain depths will benefit the growing mango seedling. The size of the selected *Borassus* plant depends on production objectives. If grown for its palm fronds, a small plant is chosen which will soon be stifled by the developing mango. If fruit and wood production are intended, a larger plant is selected which will successfully co-develop with the mango tree (Freudenberger, 1993b).

Regeneration can also result from indirect human intervention. It appears that various stands of *P. biglobosa* result from seeds deposited by soldiers, porters

and forced labourers after eating them. Such is the case of stands in Noumoudara and Koloko (Kenedougou) in Burkina Faso, which are attributed to the army of Samory Traoré, or those in villages such as Koutoura, Nianaba and Bonyolo, which are thought to have been created by the forced labour involved in the construction of the Ouagadougou-Abidjan railway (A.S. Ouédraogo, 1995; Ki, 1994).

Where appropriate, planting of parkland trees should be encouraged. Variable survival and growth performance of trees in plantations are sometimes primarily related to soil and less to genetic variability as found in an *F. albida* trial in Niger (Geiger *et al.*, 1994). In order to reduce plantation costs, increase success rates, and ensure good productivity of crops under trees, planting of parkland trees should be done selectively on high fertility microsites. These favourable microsites can be identified with farmers through growth observations of a cereal crop in the previous season and seedlings planted predominantly on these sites (van den Beldt, 1996).

Improved fallows

Improved fallows, whereby economically useful and fertility-improving trees are planted before cropping is discontinued, appears to be a promising alternative to long natural fallows.

Mineral fertilization alone is not sufficient to sustain crop yields in savanna soils, because of the degradation of physical, chemical and biological properties associated with the decline in soil organic matter content (Piéri, 1989). Fallowing therefore appears to be a necessary practice and is one of the few means available to subsistence farmers to maintain satisfactory physical and chemical soil fertility. In areas of high population pressure, however, fallows are increasingly being abandoned or reduced in length. Improved fallows aimed at the biological recycling of mineral elements and the build-up of soil organic matter seem to provide a potential alternative to long natural fallows (Harmand, 1998).

In this technique, trees are planted a few years before fields are fallowed in order to give seedlings a competitive advantage over other regenerating plant species, while not competing severely with crops. Protection from grazing and fire (and from plant competition) is necessary in fallow enrichment areas. Depommier and Fernandes (1985), for example, mention that *P. biglobosa* is one of the few species which is sometimes sown directly at the end of a rotation in order to enhance the subsequent fallow. Seignobos (1982) also mentions that in Cameroon *F. albida* is cut back every two or three years and maintained as a shrub in order to shorten fallow duration. To ensure adoption by farmers, improved fallows need to be able to generate useful products (wood, gums, fruits, fodder, etc.) during the fallow time and restore soil fertility in a shorter time than natural fallows.

In northern Cameroon, Harmand and Njiti (1998) found that *Eucalyptus camaldulensis* was not appropriate for short enriched fallows, as soil characteristics were found to deteriorate with poor incorporation of organic matter into the soil and lower soil porosity. In contrast, herbaceous fallow and *Senna siamea* had a positive effect on soil carbon, but only *Acacia polyacantha*, a nitrogen fixing species, led to a marked improvement in carbon and nitrogen content six years after planting (four-year fallow). The capacity of *A. polyacantha* to store nitrogen which is mineralized more rapidly in soil organic matter and root biomass was reflected in higher yields of subsequent crops than in other fallow types. However, the absence of a visible effect on cation exchange capacity after four years' fallow shows that fertility improvement during fallow is slow. Harmand and Njiti suggest that *Senna siamea* fallows should be converted to cultivation without the use of fire in order to conserve the system's nitrogen and that the selection of a few coppiced stems could ensure shoots for a subsequent fallow cycle. Pruning of *A. polyacantha* maintained in fields would reduce

shade and root competition with crops while providing farmers with all-purpose wood. *Acacia senegal* is another N-fixing candidate for improved fallow which is well adapted to a variety of Sudanian sites and has the advantage of generating the economic product, gum arabic, after four years.

Improved fallows apparently have good ecological and economic potential in the search for more productive and sustainable agroforestry parkland systems. Additional research is necessary to better define the processes and conditions (including species) under which improved fallows can accelerate soil fertility restoration. The integration of various forms of this technology in farming systems should also be experimented with, and management prescriptions are needed which focus on optimizing annual and tree crop production.

Fire protection

Fire in parklands can damage parkland trees directly, reduce wood and fruit production and affect the tree regeneration and fertility restoration potential of fallows. Fires in the uncultivated bush or fallows may occur at any time during the dry season and be very hot due to the presence of large amounts of fuel. In fields, however, controlled burning at the start of the dry season may be less damaging because fuel amounts are relatively low. In the Bassila region of Benin, significantly more trees were burned in the bush than in fields, although there was no significant difference in the timing of fires (Schreckenberg, 1996).

Fire tolerance in *Vitellaria* parklands is ensured by the thick bark as well as its cryptogeal germination system whereby the plumular region of the seedling is below the ground surface (Jackson, 1968). The removal of associated species by fire also influences the subsequent seed germination of *Vitellaria* individuals positively. Nevertheless, Hall *et al.* (1996) reviewed evidence indicating that, despite its fire tolerance, fire protection is beneficial to *Vitellaria* stands provided that plant competition is eliminated. When fire was excluded from areas climatically suitable for closed forest, *Vitellaria* regeneration was reduced. In

Fig. 4.3 Naturally regenerated stand of *Vitellaria paradoxa* following protection from fire and cultivation, Tolon, Ghana. *P. Lovett*

contrast, in drier conditions *V. paradoxa* stands regenerated more completely in the 20 years following clearance when fires were excluded than under an annual burning regime. Early burning in the dry season was also less detrimental to regeneration than later burning. In the Anara Forest Reserve of Nigeria, growth was vigorous in pollarded *Vitellaria* trees subject to fire, while coppicing was poor in fire-protected plots (Onochie, 1961, cited in Osei-Amaning, 1996).

Fire also has a significant effect on the time to first fruiting as well as annual fruit production. In the absence of fire, *Vitellaria* trees start producing fruit after 15 to 20 years, but fructification will take twice as long for trees which are frequently burned (Delolme, 1947). In the high Niger Valley, early fires are used to stimulate fruit production in *Vitellaria* if it stops bearing fruit for two to four years (Maguiragua, 1993, cited in Cissé, 1995). Farmers sometimes say that fire can stimulate the upward flow of sap when it is well dosed. According to Ruyssen (1957) and Hopkins (1963, cited in Hall *et al.*, 1996), flowering and leaf flush come earlier in burned than unburned trees, yet this does not necessarily imply higher fruit production. Similarly, fire had a positive effect on flowering in the Bassila region of Benin, although the average estimated fruit yields of burned and unburned trees were not significantly different (Schreckenberg, 1996). However, intense fires can also devastate fruit production. The timing of fires appears to be very important in determining their effect on fruit production. As trees are due to come into flower or have started flowering, late fires (after late January) can generally annihilate fruit yields, while there is no yield difference between sites burned early and those protected from fire, as observed in Bondoukui-Bavouhoun, western Burkina Faso (Serpantié, 1997a). People in northern Ghana also prefer early burning in order to eliminate the risk of fire during flowering (Hall *et al.*, 1996). Deposition of soot and ash on stigmatic surfaces may also impair germination and functioning of pollen grains (Osei-Amaning, 1996). Fire exclusion associated with weeding resulted in higher fruit production than a fire treatment to eliminate undergrowth (Adomako, 1985).

Parkia biglobosa is also referred to as a fire-resistant species, yet no conclusive evidence exists showing that fire has a significant effect on survival and reproduction (Hall *et al.*, 1997). In Bassila, Benin, heavy fire damage was associated with no flowering at all, while light burning after bud formation did not have a negative impact on fruit production (Schreckenberg, 1996). Local farmers believed that *P. biglobosa* as well as *Tamarindus indica* produce better in the total absence of fire. In Burkina Faso, *Parkia* trees are often protected from bush fires by removing fuel, flattening the grass and establishing belts of green vegetation around the trees (Ki, 1994). For instance, Gourmantché labourers may be paid to cultivate a piece of land around stands of trees which will serve as a fire-break or simply to clear the area around individual trees. The Gourmantché, Lobi and Bobo practise early burning and flatten the grass to keep flame height low. The use of green vegetation belts around trees is also practised among Gourounsi farmers. Although more intensively used for stands of *P. biglobosa*, some of them are also applied to individual trees.

The immediate effects of burning on top-soil nutrient availability are generally positive, but nutrient loss through volatilization, leaching and wind and water erosion can also prevail. Fire control leads to more nutrients being stored in the woody biomass than in the soil, and reduces mineral cycling. It contributes to an increase of woody plant diversity, canopy cover and productivity in the Sudan zone (Breman and Kessler, 1995). Bush plots protected from fire for three years produced over twice as much woody biomass as unprotected plots in the Sudan zone of Cameroon (Peltier and Eyog-Matig, 1989). Burning was recommended after an *Eucalyptus camaldulensis* fallow in Cameroon to

compensate for poor organic matter incorporation into the soil (Harmand, 1998). However, fire did not significantly improve soil chemical properties after *Senna siamea* and *Acacia polyacantha* fallows, which are characterized by higher external recycling of nitrogen and mineral elements. Fire can be beneficial on nutrient-deficient ferralitic soils in humid zones where minerals are immobilized in above-ground plant compartments. Breman and Kessler (1995) recommend that burning should be avoided as much as possible in the Sahel region. Instead, field clearance residues should be spread over the fields as mulch after the largest woody parts have been removed.

Silvicultural techniques

To increase production of parkland trees, sahelian farmers commonly protect, fence and water seedlings, select vigorous shoots and prune trees.

After their selection and protection, the development of parkland trees is aided by traditional silvicultural techniques. Farmers usually weed the area around chosen individuals. Young *P. biglobosa* trees are generally protected from animals by a barrier of branches, straw or thorns in Burkina Faso (Ki, 1994). Planted or valuable naturally regenerated trees in the residential area can also be watered. Close to half of 230 farmers interviewed in central Mali reported that they practise one or more tree maintenance techniques including pruning, fencing, watering and manuring (McLain, 1991a). To ensure rapid *F. albida* seedling establishment and growth to a desired shape, farmers will clean small saplings of branches which could pull them down (Montagne, 1984). In Burkina Faso, Janodet (1990) reported that some farmers cut the seedlings to the ground in the first year and cut all but the most vigorous stem in the second year in order to develop a strong taproot. *Faidherbia albida* shoots can be very bushy in parklands because seedlings or suckers are repeatedly browsed by livestock in the dry season and even cut back annually by farmers during the rainy season. In the meantime, the root system develops vertically until it reaches the aquifer, and a selected shoot will grow rapidly above ground past browsing height if deliberately protected. In contrast, *F. albida* has an ascending tree architecture in plantations (Peltier's note, in Seignobos, 1996). Seignobos (1982) also noted that where high densities of bushy *F. albida* occur, farmers can easily establish parklands by selecting a single branch on these trees if land for cultivation is needed.

Pruning/debranching

The purpose of pruning (cutting back certain branches) may include wood, fodder and mulch production, improved fruit production, reduction of shade on understorey crops, longer tree lifespan, as well as control of parasitic plants such as *Tapinanthus* spp. in affected species. However, as discussed in Chapter 5, these benefits are often not recognized by outsiders, including foresters.

Pruning of *P. biglobosa* is common in Nigeria (Tomlinson *et al.*, 1995) and was practised on 10 to 30 percent of all *Parkia* trees in 21 villages on a north-south transect in central Burkina Faso (Timmer *et al.*, 1996). Its main purpose now in Burkina Faso is to improve tree survival and productivity especially in the northern sites, whereas its primary function used to be for wood exploitation and to reduce the tree's influence on the environment. This indicates that *Parkia* fruits themselves represent an increasingly important resource worth managing for. Most pruning activities take place in April and May rather than after the rainy season on trees older than 30 years. Light pruning (removing one or several main or secondary branches) was as frequent as intensive pruning (removing most or all main branches). With increasing tree age farmers tend to prune trees more intensively and more often, with the aim of rejuvenating them and reducing

shade. Pruning is also more intense in village fields and valleys than in bush fields and slopes, probably because trees are better protected and manured, or produce more fruit there. The fear of forestry agent sanctions, the time lag needed (at least three years) for enhanced fructification, the lessened tree resilience in drought years, and potential tree tenure conflicts were the primary reasons for not pruning more extensively.

Lopping (pruning of smaller branches and twigs, often for fodder) is commonly practised in *F. albida* parklands which include a pastoral component. In Watinoma and Dossi, Burkina Faso, two villages with high and low livestock and herder population densities, respectively, lopping was practised on 50 percent and 25-30 percent of *F. albida* trees (Depommier and Guérin, 1996). Excluding small diameter trees, which are generally not pruned, pruning frequency on larger trees was 70-80 percent in both villages. Pruning intensity, or canopy reduction, increased with higher grazing pressure as well as with increasing proximity of residence. In Sob, Senegal, *F. albida* canopies had been heavily reduced between 1965 and 1985 by 38 percent on average (13 to 66 percent) (Louppe *et al.*, 1996). They are also heavily lopped in Sudan (Miehe, 1986). In central Burkina Faso, pruning takes place mostly during the second half of the dry season, culminating in March-April when fodder is most needed. After an early dry season operation, farmers/herders may prune large trees again at the end of the dry season to harvest the very nutritious and palatable new shoots.

Repeated pruning of *F. albida* tends to stimulate leaf production. In Burkina Faso, leaf regrowth one year after total pruning, which was correlated with canopy size, was complete where trees were regularly pruned but reached only 60-80 percent of previous leaf biomass where pruning was not practised systematically (Depommier and Guérin, 1996). Pruning resulted in an increased ratio of leaf biomass to total biomass and a canopy area reduction of 10-40 percent. Regular pruning also appeared to increase canopy regrowth capacity as shoot diameters were up to twice as large where it was practised. In Burkina Faso, pruning resulted in a two to three month delay of *F. albida* phenology. When it was carried out in the second half of the dry season, leaves appeared at the start of the rainy season, fell in the second half and grew again in the following dry season. Pruning also induces tree rejuvenation and causes older spineless trees to grow spines. Overall, *F. albida* responds very well to pruning when this is not excessive. Cissé (1984) recommended a single pruning operation early in the season. Contrary to its effect on leaf biomass, however, pruning has a drastic negative effect on pod production. This was reduced by up to ten times between 1994 and following intense pruning in 1995 in Burkina Faso.

Fig. 4.4 Lopping of *Faidherbia albida*, Ngaparou, Senegal. ***P. Danthu***

Pruning of *V. paradoxa* is less common than that of *F. albida* and *P. biglobosa*. *Vitellaria*'s slow growth rates are reviewed by Hall *et al.* (1996). Pruning is considered to be either not suitable (Kessler, 1992) or to have uncertain effects (Kater *et al.*, 1992). Farmers claim that pruning will reduce fruit yields (Kessler, 1992). However, some large individuals in Nigeria respond very vigorously to

pruning (Brun, 1996). The species also responds well to coppicing. Individuals of 15-30 cm diameter showed vigorous stump shoots (Chevalier, 1948). In southern Burkina Faso, lower branches up to 15 cm diameter had been cut off at their base in 56 percent of a large sample of *V. paradoxa* trees. This was done in order to allow manoeuvring of draft animals and/or improve tree form for the production of understorey crops rather than to stimulate tree growth or fruit production (Boffa, 1995). Bagnoud *et al.* (1995a) also report that the lower branches of *Vitellaria* and *Parkia* trees are pruned every two to four years to form ascending crowns in young trees and to afford more light to crops in older ones.

When growing on croplands, *Detarium microcarpum* is occasionally pruned to reduce shade over crops and to promote fruit production (Wiersum and Slingerland, 1997). Farmers in Ndam Mor Fademba, Senegal, also report that they prune *Combretum glutinosum* and *Guiera senegalensis* shrubs to hasten tree regeneration for firewood collection or to enhance agroforestry associations (Schoonmaker and Freudenberger, 1992). In northern Cameroon, *Prosopis africana* is systematically pruned in parklands before the rainy season in order to allow more light penetration for crops underneath. Excessive pruning intensity may be one of the causes of parkland degradation in this area (Bernard, 1996). *Hyphaene thebaica* and *B. aethiopum* are also lopped to supply palm fronds (Seignobos, 1982). Finally, *Quercus rotundifolia*, *Quercus suber* and *Quercus faginea* trees in the dehesa agroforestry systems of Spain are often pruned for improved acorn and wood production (Joffre *et al.*, 1988).

Research on *Tapinanthus* species, epiphytic plant parasites of *V. paradoxa* as well as a variety of other parkland species, shows that pruning is currently the quickest and cheapest way to rid trees of this threatening pest. Tree limbs affected by the parasite should be cut above the infected site in order to eliminate the parasite's whole absorption system (Boussim *et al.*, 1993b). Given the high proportion of trees affected and the wide zone of occurrence of *Tapinanthus* species, such measures are urgently needed and should be widely recommended by extension services.

Ringing

Ringing is another traditional practice used for stimulating fruit and seed production. It was observed in several instances on *P. biglobosa* in Burkina Faso (A.S. Ouédraogo, 1995; van der Vleuten, 1995, cited in Wiersum and Slingerland, 1997). When optimally done, a shallow 10 cm-wide ring of bark is cut from the trunk at breast height just before flowering. This technique is used on *Parkia* trees which farmers identify as producing no fruit or producing seedless fruit, and can also be combined with pruning. It is assumed that ringing favours flowering and fruit production to the detriment of vegetative production by blocking the transport of assimilates or changing the concentration of gibberelline growth hormones (Tromp *et al.*, 1976; and Costes, 1983 cited in Wiersum and Slingerland, 1997). In the high Niger Valley farmers also practise 80 cm longitudinal cuts on *A. digitata* and introduce rock salt in order to stimulate growth (Maguiragua, 1993, cited in Cissé, 1995).

Coppicing and pollarding

Depommier and Fernandes (1985) report that parkland species (no particular species mentioned) in landscapes dominated by *Vitellaria* and *Parkia* species in the Central African Republic can be coppiced (cut at the base to encourage bushy shoot regrowth) and pollarded (cut above grazing height to encourage

shoot regrowth) to limit crop yield depression or for gathering wood and other tree products, or even to provide support for yam vines. Trees in fields left to fallow are also managed for fuelwood production by coppicing. Grigsby and Force (1993) state that in the Upper Niger River Valley region of Mali, women coppice regenerating trees on three to five year rotations to obtain diameters equivalent to the size of a fist. Two or three rotations of fuelwood can be produced in the course of a fallow period allowing the restoration of soil fertility. Neem (*Azadirachta indica*) is commonly coppiced every year before the rainy season; it is used for fuel and construction wood and the leaves and smaller branches are sometimes used for mulching (Yelemou *et al.*, 1993). In alley farming, sorghum yields were highest close to trees coppiced early and lowest close to trees coppiced late (Tilander *et al.*, 1995). *Detarium microcarpum* is actively managed for production of wood which is particularly valued for construction purposes (van der Vleuten, 1995, cited in Wiersum and Slingerland, 1997). For this species, farmers assist in the growth of a single vertical shoot by cutting the others and regularly stripping the plant of lower leaves, side branches and other shoots. Once they reach usable size, *Detarium* plants can be coppiced repeatedly for several years. Pollarding of *Ceiba pentandra* was also reported in parklands outside the city of Zaria, Nigeria (Pullan, 1974). *Faidherbia albida* parklands of Masa country in northern Cameroon are associated with a layer of systematically pollarded *Ziziphus mauritiana*. Harvested wood and branches are used as construction poles and as material for fences erected to surround compound fields and channel livestock movement (Seignobos, 1996).

Fig. 4.5 Pollarded *Azadirachta indica* among *Faidherbia albida* trees in village fields of Dissin, Yoba Province, Burkina Faso.
S.J. Ouédraogo

Fig. 4.6 *Faidherbia albida* parkland with substratum of *Ziziphus mauritiana* trees, Yagoua, Cameroon.
C. Bernard

Tree fertilization

One could expect a similar positive effect of organic and/or chemical fertilizers on tree (wood and fruit) production to that observed on domesticated orchard species. Currently, priority use of available fertilizer resources is usually directed to crop rather than tree yield improvement. Little information exists therefore on this topic. Nevertheless, Simond (1930, cited in Hall *et al.*, 1996) mentioned that the use of 5t/ha of cattle manure increased *Vitellaria* fruit yields by an average of 38.6 kg per tree. Hall *et al.* (1996) also cited a study conducted by Osei-Bonsu (1991) in which seedlings in tilled plots displayed

better height (but not diameter) performance (mean height 6.28 cm) than those in zero-tilled plots (mean height 4.12 cm), but which was not visible before the third year of the experiment. The excavation of a space between roots of *P. biglobosa* to stock water during the rainy season was observed among the Gourounsi in Burkina Faso. This is done to remedy possible rainfall insufficiencies (Ki, 1994). The same author encountered indigenous pest-control operations in which a sharp object is introduced in sites of worm infection. A few farmers also used toxic products against insect attacks.

Manuring and application of rock phosphate in conjunction with mycorrhizal inoculation can benefit tree establishment and production.

Because of the common phosphorus deficiency of West African soils, research has also focused on the use of phosphorus fertilizers in conjunction with endomycorrhizae for better tree development. By expanding the volume of explored soil, infection with endomycorrhizal fungi stimulates *F. albida* growth (Ducousso and Colonna, 1992). Bâ *et al.* (1996) showed that non-inoculated *F. albida* seedlings can make direct use of Burkina Phosphate, a locally available natural tricalcic rock phosphate. However, inoculation with the endomycorrhizal fungus, *Glomus aggregatum*, significantly increases the efficiency of phosphate use. Inoculated seedlings displayed increased growth, phosphorus and nitrogen content, and a lower root/shoot ratio. Increased doses of rock phosphate increased phosphorus content in stems of inoculated seedlings but had no effect on their height.

Management techniques for improved crop production

This section focuses on tree-based techniques for improving crop production. Numerous references to soil and water conservation techniques (Reij *et al.*, 1996), such as earth and rock bunds (Rochette, 1989), grass strips (Renard and van den Beldt, 1990) and *zai* (Lowenberg-Deboer *et al.*, 1994) can be found elsewhere.

Pruning and coppicing

The possibility of increasing solar irradiation and taking advantage of nutrient enrichment around trees is a strong argument in favour of pruning parkland trees. Pruning *P. biglobosa* resulted in higher sorghum yields relative to unpruned trees (Kessler, 1992). In Senegal, pruning inverted groundnut productivity trends with increasing distance from *Cordyla pinnata* trees. Total biomass was 1 486, 2 084 and 2 110 g/m^2 around unpruned trees, while yields were 2 177, 1 829 and 1 787 g/m^2 for pruned trees (Samba, 1997). The same patterns were observed on *Azadirachta indica* in Saria, Burkina Faso. Sorghum grain and straw yields under the canopy of pruned trees were higher than at the distances of 1 and 3 radii, and yields under pruned canopies were higher than under unpruned trees (Zoungrana *et al.*, 1993). Coppicing resulted in similar and significant grain yield increases around *A. indica*. Yields were 48 and 33 percent higher under and directly outside canopies (coppiced before planting) than in the open field (Tilander *et al.*, 1995). Improved environmental conditions would appear to outweigh below-ground competition, which is possibly intensified with root morphology changes resulting from pruning (van Noordwijk *et al.*, 1991, cited in Rhoades, 1995).

The effect of pruning *F. albida* on understory crop production has not been quantified so far. If nutrient inputs from leaf litter are primary factors for the '*F. albida*' effect, one would expect repeated pruning to reduce or cancel this effect on crop productivity when compared with unpruned trees. According to Louppe

(1990, cited in Depommier *et al.*, 1992), pruning *F. albida* has a negative impact on crop production underneath. However, yield improvements have also been observed in the proximity of pruned *F. albida* trees (Depommier and Guérin, 1996). These authors suggest that the effect of pruning would need to be verified on parkland trees which have not been subject to pruning since establishment. This may be accomplished better on station than on farm.

The above data indicate that pruning offers good potential for improving crop yields under trees which would normally reduce them. At the same time, if carried out in moderation, pruning of *F. albida* need not necessarily reduce the tree's benefits too greatly. Data reviewed in earlier sections also suggest that the proportion of trees subject to this practice is moderate in the region, especially for species other than *F. albida*, and could therefore be extended. However, little is known of the influence of annual pruning on nutrient cycling and fertility of sub-canopy soils, as well as crop performance, especially in the long term.

Research addressing these issues will be instrumental in establishing precise recommendations for appropriate pruning intensity, frequency, and time according to species, tree age, latitude and rainfall conditions. Such studies should result from additional experiments as well as thorough investigation of indigenous knowledge in this area. As pruning may not only improve crop yields but also reduce potential fruit, leaf and wood production, studies need to investigate both these aspects in order to provide farmers with management prescriptions best suited to their production objectives.

Organic inputs are necessary to maintain soil fertility in semi-arid West Africa. Positive results have been achieved with application of* Azadirachta indica *or* Acacia lebbek *leaf mulch.

Organic fertilization and mulching

Poor soil fertility is a primary constraint limiting crop production in semi-arid West Africa, even outweighing moisture deficiency in the long run (Bationo and Mokwunye, 1991a). In this area, the purchase of mineral fertilizers is generally limited in subsistence-oriented farming systems, leading to soil degradation through a decline in exchangeable bases, acidification and aluminium toxicity when used alone (Piéri, 1989). Research has therefore stressed the benefits of various organic additions such as crop residues and the applications of straw, compost and manure to increase the fertility of agricultural soils (Bationo and Mokwunye, 1991b). The use of manure and compost is, however, limited by livestock numbers and straw availability, and could be complemented with tree mulch.

Some years ago the use of organic material (household refuse, crop residues, animal manure) tended to be restricted to compound fields. More recently, farmers appear to be managing a larger area of more distant fields in a more intensive manner including the application of organic and chemical fertilizers (Vimbamba, 1995; Seyler, 1993). Some degree of manure/compost use is reported in most studies, e.g. in *Vitellaria* parklands closest to settlements in Mali (Baumer, 1994), in *F. albida* parklands in Burkina Faso (Depommier *et al.*, 1992), in *F. albida* and *Adansonia* parklands north of Kano, Nigeria (Pullan, 1974), etc. It is transported to the field, dumped in piles and then spread evenly over an area with a radius of a few metres. In Senegal, manure is applied not at random but particularly in areas deemed infertile, and not under and around *F. albida* trees where production is favourable (Seyler, 1993). In areas where sources of organic matter have become scarce, farmers resort to collecting grass during the dry season which they spread in fields as mulch (Lowenberg-Deboer *et al.*, 1994).

The application of tree mulch in crop fields is recognized as another way of maintaining or enhancing soil fertility in these systems. In semi-arid Burkina

Faso, leaf mulch from *Azadirachta indica* (3.7 t dry matter/ha) or *Albizia lebbeck* (2.7 t dry matter/ha), corresponding to 75 kg nitrogen/ha enhanced sorghum yield up to fourfold (Tilander, 1993). The mulch effect on yields increased over the three years of application and was more pronounced with higher dosage. Smaller leaf quantities (25 to 50 kg nitrogen/ha), corresponding to the production of an alley-farmed field, also had a significant positive influence on yields in most cases. In addition, yields monitored on an annual basis were not sensitive to mulch composition (*A. indica*, *A. indica* + straw, or *A. lebbeck*), but over the three-year period *A. indica* leaves were superior to the two other mulch types. Timing of application also influenced yields in a way which seemed to vary according to rainfall distribution. In Malawi, highest quantities of inorganic nitrogen derived from annual *F. albida* litter and root inputs became available with the first rains. However, Rhoades (1995) noted that this period of nitrogen availability occurred before full crop root development and that the highly mobile nitrates may have leached below the crop root zone, thus bypassing crops completely. He therefore recommended the mixing of easily decomposed and nutrient-rich litter with resistant (high lignin content) plant material to favour a more gradual nutrient release.

Tilander also showed that *A. indica* mulch contained a higher amount of nutrients and showed release rates higher than (for nitrogen, calcium and magnesium) or similar to (for potassium) *Acacia holocericea* leaves (Tilander, 1996). Both nutrient-rich (*A. indica* leaves and *A. indica* leaves + compost) and nutrient-poorer mulches (wild grass and *A. holocericea* phyllodes) resulted in significant water conservation and temperature reduction. However, there were higher yields in nutrient-rich (*A. indica* leaves, *A. indica* leaves + compost, and compost alone) treatments than in other plots with nutrient-poor mulches. Highest yields were achieved with mulches combining high nutrient delivery as well as moisture conservation and temperature reduction. In the range of mulches tested, *A. indica* leaves performed best.

Fig. 4.7 Manure or compost is heaped and will be spread uniformly throughout the fields.
R. Faidutti

Samba (1997) reported a nursery experiment in which the application of 39, 78 and 156 kg of *Cordyla pinnata* litter/t of soil increased total millet biomass 17, 1.9 and 1.5 times over the control, but resulted in total peanut biomass decline of 11, 13 and 29 percent, respectively. According to Cissé (1995), leaves of *V. paradoxa*, *F. albida*, *Khaya senegalensis*, *Daniella olivieri*, *Isoberlinia doka*, *Pterocarpus erinaceus* and *Afzelia africana* have a fertilizing effect. They are harvested and composted with millet residues and manure. Foliar biomass production for *V. paradoxa* (mean dbh=42 cm) and *Bombax costatum* (mean dbh=39 cm) in parklands was estimated from litter sampling at 29.5 and 23 kg/tree, respectively, in southern Burkina Faso (Bambara, 1993). An estimate of *Cordyla pinnata* leaf production in parklands of the southern part of the Peanut Basin of Senegal was 337 kg/ha (Samba, 1997). Assessments of foliage production reviewed in Breman and Kessler (1995), and considered in

Chapter 6, mostly focus on woody species of the Sahel zone of West Africa. In the same reference, nitrogen and phosphorus foliage concentrations are tabulated for a larger spectrum of woody species.

Preliminary data suggest that tree mulch can contribute to sustained crop production in agroforestry parklands, but that this requires more intensive tree management than commonly found on-farm. Additional research in this area should assess what amounts of nutrients can be expected from parkland leaf mulch according to species and density, as well as defining for an extended number of parkland species how (application timing, short- and long-term effects, etc.) application of leaf mulch contributes to soil protection and productivity goals. These findings could eventually lead to technical prescriptions of intensified parkland management including pruning regimes and optimal tree densities according to climatic zones and soil type. Of similar importance, the costs, benefits, and practical feasibility, in terms of labour and access to tree resources, of tree-harvesting and mulching practices also need to be considered.

Tree/crop associations

Higher soil fertility and improved microclimatic conditions (see previous chapter) under *F. albida* canopies present a more favourable agroecological environment for crop growth. Williams (1992) hypothesized that the conditions created by *F. albida* allow the planting of (cash) crops not otherwise common in the Sahel because of their lack of adaptation to high temperatures and low soil fertility. Gains from intensive cropping around trees would promote farmer interest in intensive tree management. Trials with maize and cotton under *F. albida* have been conducted in Sadoré by ICRISAT (van den Beldt, 1996). Dancette (1968) suggested that fields could be laid out in between *F. albida* rows, with cereals grown in tree rows and groundnuts in the alleys. Farmers do allocate specific crops to sub-canopy environments. Aware of the more pronounced effect of *F. albida* on millet than on groundnut production, farmers traditionally cultivated millet under *F. albida* even in groundnut fields in Sob, Senegal (Louppe *et al.*, 1996). Where millet is a regular field crop, higher priced crops such as tobacco and sorghum are sown under *F. albida* canopies in the Madaroumfa area of Niger (Montagne, 1996).

The sowing of crops or crop mixtures demanding higher soil fertility and moisture or tolerating shade in the proximity of *Vitellaria* and *Parkia* trees has also been recommended (Kessler, 1992; Kater *et al.*, 1992). Farmers often choose to grow tobacco, cassava, yam, sweet potato and large-leafed vegetables under these trees (Teklehaimanot *et al.*, 1997; Kessler and Boni, 1991; Janodet, 1990; Wiersum and Slingerland, 1997). Besides making more efficient use of microenvironmental conditions, farmers diversify resources and reduce the risks of crop failure through such tree-crop associations.

Fig. 4.8 Association of a local tuber crop, '*fabirama*', with a *Parkia biglobosa* canopy, Thiougou, Burkina Faso. ***J.-M. Boffa***

However, these crops are not cultivated on a large scale, because of low demand and time-consuming weeding requirements (Kessler, 1992). Although this technology may not be uniformly applicable on a large scale, research aimed at identifying optimal crop-tree combinations and the technical and socio-economic conditions required for their adoption is necessary.

Genetic improvement of parkland species

Planting trees is still a limited practice in the Sahel. In addition to a number of possible social and economic factors (discussed in later chapters) farmers have apparently been discouraged from doing so by several biophysical characteristics of indigenous tree species. Parkland species may have a slow growth rate, and a long juvenile phase before fructification. Thus, farmers feel that they will not benefit from planted trees during their lifetime and would rather rely on trees occurring naturally. In addition, because parkland trees are wild, average tree production is low and production of pods/fruits is highly variable from one individual to another and from year to year. For instance, pod/fruit production varies by a factor of 10 between consecutive years and between trees in *F. albida* (Depommier, 1996b), and by a factor of 5 between an average and best producing *V. paradoxa* (Boffa *et al.*, 1996a) in Burkina Faso.

Recently, there has been an increasing interest in domestication of agroforestry trees (Leakey and Newton, 1994). Domestication is defined as human-induced change in the genetics of a plant to bring it into wider cultivation through a farmer-driven or market-led process (Harlan, 1975; Simons, 1997b). Resulting in the delivery of improved trees, it has the potential to increase farmer interest in managing (cultivating) parkland trees more intensively as well as contributing to the productivity and sustainability of these systems. However, there is a limited understanding of the sort and quantities of tree germplasm needed as well as its impact on the adoption of parkland agroforestry practices. A major challenge in realizing the potential held in the domestication process depends on whether the resulting improved germplasm fulfils farmer needs. While the potential positive effects of domestication seem good because of the large variation existing within parkland species, farmers' decision-making processes concerning tree planting and management practices are still poorly understood (Simons, 1996).

Fig. 4.9 Rooted hardwood cutting of *Vitellaria paradoxa* with new flower bud formation.
P. Lovett

Fig. 4.10 'Timber' variety of *Vitellaria paradoxa* growing in cleared woodland, Bomburi, Ghana.
P. Lovett

Domestication strategies for individual species vary according to their uses, biology and target environments and vary in intensity on the continuum from the wild to the genetically transformed (Simons, 1997a). A central preoccupation of domestication work at

ICRAF has been to assess user needs and preferences related to tree species. Priority-setting guidelines including the various stages leading to a gradual reduction of species considered have been made available (Franzel *et al.*, 1996). In Senegal, Mali, Burkina Faso and Niger, farmers were asked to rank 15 preferred species. The 28 species identified out of the potential 60 show that there are common interests across the region. Top species for the whole region included *Adansonia digitata*, closely followed by *V. paradoxa* and *Tamarindus indica* (ICRAF, 1995a). Only two exotic species (*Azadirachta indica* and the now almost indigenous *T. indica*) were cited, suggesting heavy farmer reliance on and appreciation of local species.

The exercise showed marked differences among social groups, such as men and women, as well as younger and older men, and emphasizes the need to identify target groups clearly. Species selection is also dependent on purpose (conservation, subsistence, income generation, etc.); thus *Bauhinia rufescens* and *Prosopis africana*, which are among the most threatened and important fodder species, did not figure in the 15 top species. There are currently no comprehensive data comparing the economic, social and environmental costs and benefits of domesticating species occurring in forest systems with those of species found on farms. Until this knowledge gap is bridged, priority will tend to be given to farm species for which at least some biological and social information is more readily available (Simons, 1996).

The first steps toward the domestication of several West African parkland species have taken place in past years. Assessment of genetic diversity has been ongoing for *F. albida* in the last two decades (CTFT, 1988; Leakey and Newton, 1994; Bastide and Diallo, 1996). For *P. biglobosa*, germplasm conservation and evaluation activities, among others, have been carried out recently through an EU-funded project (Teklehaimanot *et al.*, 1997). Germplasm collections of *V. paradoxa* were undertaken in 1985-1986 (Adu-Ampomah *et al.*, 1995) and more recently in Ghana (Lovett, 1999; Lovett and Haq, 1999a), as well as in Burkina Faso, Senegal, Mali and Uganda through ICRAF. *Prosopis africana* seedlots have also been collected in SALWA countries, and *B. aegyptiaca* in Niger (ICRAF, 1994; Tchoundjeu *et al.*, 1998). Evaluation and improvement activities on *A. indica* including collections in Ghana, Senegal and Tanzania have taken place within the International Neem Network (Thomsen and Sigaud, 1998). The understanding of vegetative propagation varies from species to species and some details are presented in Box 4.1.

Because the domestication process starts with farmers, the approach used to improve agroforestry trees presents not only biological but also socio-economic and political challenges. This is a departure from traditional industrial tree breeding and requires different methods. Focus is placed on the rapid availability of high quality germplasm for a diversified

Fig. 4.11 'Erect' variety of *Vitellaria paradoxa* in farmed parklands, Sawla, Ghana.
P. Lovett

Fig. 4.12 'Dwarf' variety of *Vitellaria paradoxa* with fruit in farmed parklands, Tolon, Ghana.
P. Lovett

and stable production rather than the lengthy process of high selection intensity through generations of provenance and family trials. Generally speaking, depending on species and location, improvement should seek to enhance the quality of tree products, tree growth rate and pest resistance, and ensure species adaptability to potential planting sites (including minimal competition with crops) (Simons, 1997a). Rapid delivery of germplasm also requires that successful propagation techniques are developed in advance of the identification of elite material, so that germplasm displaying superior performance in identified priority traits is made available when demand is incipient. As long as characteristics and functions of trees desired by farmers are not comprehensively surveyed, germplasm with the largest possible genetic variation should be promoted.

For each species under consideration, the question is whether domestication is worthwhile and which strategy should be followed. Decision-making frameworks are needed which take into account the large and complex range of determinants involved (Simons, 1996). An important criterion justifying investment in a selection and seed production programme is the pre-existing demand for the species, and particularly whether the species is currently planted or not. Data presented in Chapter 7 show that markets for parkland products are substantial in terms of volume of products and income. Among other factors, market value depends on

Box 4.1

Advances in the vegetative propagation of some parkland species

Faidherbia albida

Vegetative propagation of *Faidherbia albida* is easily achieved through root cuttings (De Fraiture and Nikiéma, 1989). Rooting results are more successful using the basal part of shoots/branches of young individuals, collecting them during the rainy months between June and September, with cuttings grown in a 2:1 sand:compost mixture (Nikiéma and Tolkamp, 1992). While the use of Indol-3-butyric acid (IBA) hormone did not produce better root emergence, it did result in more and longer roots per cutting than controls. Propagation of adult *F. albida* was also achieved with lignified branch cuttings 7-15 mm in diameter collected at the bud-breaking stage, as well as with inverted root fragments (Danthu, 1992). *In vitro* propagation of *F. albida* is also easily realized from cotyledon buds (Duhoux and Davies, 1985), but is difficult with microcuttings from root suckers of adult trees (Gassama, 1989). However, Detrez and colleagues (1992) succeeded in grafting *in vitro* meristems of both juvenile and adult *F. albida* plants on rootstock obtained from seed. While shoots have been micropropagated on rootstock, techniques are needed for root formation.

Ouédraogo (1993) evaluated the relative performance of plants grown from cuttings, poly-bag seedlings and direct seeding. Cuttings displayed the highest vertical growth and collar diameter after 42 months of outplanting. This is due to their prolific early tap root development induced in the nursery which resulted in the rapid efficiency of water and mineral nutrition. However, their mortality was higher at 42 weeks than for plants resulting from direct seeding or raised in pots. Directly seeded trees are well adapted to drought. They can reach deep water rapidly through the development of a deep taproot, and reduce their water needs by keeping their above-ground part limited to a dormant ground-level bud. Thus, for genetic improvement, vegetative propagation through cuttings can rapidly produce vigorous material, provided growing conditions are favourable. In contrast, direct seeding permits higher establishment success under harsh field conditions.

Parkia biglobosa

Parkia biglobosa is a relatively easy-to-root species; in six to eight weeks 40 percent of cuttings rooted and the survival rate was 80 percent without any inducing factor (Teklehaimanot *et al.*, 1996a). Rooting and survival of juvenile plants were significantly influenced by nodal position on the shoot, basal wounding, auxins and provenances. Rooting was highest in cuttings obtained from terminal nodes and declined gradually down the shoot. Wounding in the form of a diagonal cut is recommended for enhanced rooting ability. *Parkia biglobosa*

the relative lack of tree products due to the degradation of forest cover, and the relative economic profitability of tree regenerating practices.

Elements of the parkland classification presented in Chapter 1 can therefore be used to distinguish parkland and/or species types in order to establish general domestication strategies. Proto-arboricultural and planted parklands, where people already plant, transplant or deliberately disseminate species, may be the easiest target for domestication. Where they occur, a growing farmer demand will 'only' require improved germplasm with markedly superior performance. The case of *Borassus aethiopum*, which is actively harvested and (trans-) planted for food security and income generation, is a prominent and promising example. Farmers may also be keen to use improved germplasm of *Azadirachta indica*, and possibly *Adansonia digitata*, both of which they already actively regenerate. In each case, the improvement threshold will need to be defined with farmers in the context of other decision-making parameters.

Whether farmers perceive differences between individuals of the same species is central to the potential impact of tree improvement. Forms of domestication practised by local people and associated indigenous knowledge on genetic diversity should be a point of departure for genetic improvement research. Farmers vary in their appreciation of intraspecific variation, but much indigenous

also rooted better in the presence of auxins although this depended on provenances. 100 ppm of the plant hormone Napthalene acetic acid (NAA) was more effective than 100 ppm IBA, but this was reversed at 200 ppm. The Derived Savanna provenance was the most vigorous and easiest to root. The Guinea provenance was the most difficult to propagate, but it responded well to high concentrations of combined auxins. The Sudan provenance displayed highest rooting success with wounding alone. Similar experiments on adult plants are recommended.

Single node cuttings of *P. biglobosa* also rooted in non-mist propagators (Teklehaimanot *et al.*, 1996b). However, their survival was low (26 percent). Use of higher concentrations of auxins and more careful weaning are suggested to increase rooting success. Shoot and root initiation and elongation of *P. biglobosa* with tissue culture were also successful using mixtures of Indol-3-acetic acid (IAA), IBA and K hormones in various media (Teklehaimanot *et al.*, 1996b). Air layering was also achieved. In contrast, efforts at inducing precocious flowering in the species were not successful.

Vitellaria paradoxa

As opposed to the preceding two species, seeds of *Vitellaria paradoxa* are recalcitrant (i.e. have very short viability). Germination rates decline from 95 to 35 percent when seed moisture content is reduced from around 40 to 20 percent, or decline to 0 if moisture is further reduced (Gaméné, 1998). Natural seed viability is generally limited to a week and at most a month (Ruyssen, 1957), but reached four months in wood sawdust before germination at the *Centre national de semences forestières* (CNSF), Burkina Faso. Grafting is difficult but can be successful, provided grafts are not water-stressed and that latex does not block the graft stock union. Maintaining high humidity in non-mist propagators and soaking scions in water for over 30 minutes to remove excess latex gave a 25 percent success rate (Grolleau, 1989). Root development in 42 percent of *Vitellaria* cuttings was obtained using 1.5 percent IBA and IAA hormones (Frimpong *et al.*, 1993). These results were achieved with semi-hardwood cuttings which rooted more frequently than either hardwood or softwood cuttings. A pure black soil or a sand and rice husk mixture is appropriate. Time of year when cuttings are taken and conditions during transportation to the propagation laboratory also had an influence on rooting results. A rooting success rate of 80 percent was obtained after 90-120 days, using stem cuttings from hardwood, softwood and coppice shoots of mature trees (Opoku-Ameyaw *et al.*, 1997). A 100 percent success was obtained when over 50 rooted cuttings were transferred to the field, although a loss of 20 percent occurred during transfer to polybags and during the hardening period. It has also been possible to establish, multiply and root apical shoots of Vitellaria seedlings *in vitro* (Lovett and Haq, 1999b).

ethnobotanical knowledge still needs to be investigated. In *V. paradoxa* parklands, regenerated through cycles of cultivation and fallow, farmers carry out some selection, not only at clearing time but also in later years. One-quarter of a farmer sample in Thiougou, Burkina Faso, distinguished unproductive *Vitellaria* trees on the basis of tree condition (trunk with burn patches or base openings, diffuse or partially dead foliage), nut, leaf and bark characteristics, as well as the amount of nuts found under trees (Boffa *et al.*, 1996b). Narrow leaves are considered a distinguishing sign of a '*tam daaga*' variety, which produces small and nutless fruit, while the nuts of individual *Vitellaria* trees called '*zoonpela*' fall before maturity. The remainder of the sample reported that they eliminate individuals which do not produce well, based on an evaluation period of two to six years. It is probable, therefore, that farmer selection over many generations has led to some degree of domestication in this and other parkland species (Lovett and Haq, 1999c).

Farmers are generally aware of the diversity which exists in highly valued parkland species. Throughout West Africa they recognize a variety of trunk, fruit, seed, pulp, flowering and fruit production characteristics in *P. biglobosa*. Two

Box 4.2

Is there a case for improvement of Vitellaria paradoxa?

Perhaps because *Vitellaria paradoxa* kernels are one of the few parkland commodities traded internationally, marketing data are more readily available than for other parkland species (see Chapter 7). Several sources suggest that both potential and actual supplies of *V. paradoxa* kernels in West Africa exceed local and international demand. In Mali, only 39 percent of nuts were collected in the 1970s (Hyman, 1991). Richard (1980) estimated that roughly half of the 40-50 000 tons of the *Vitellaria* kernels which Côte d'Ivoire can produce is exploited. A general estimate cited in Schreckenberg (1996) is that 60 percent of West African production is not being utilized.

Location may be a key factor in determining whether *Vitellaria* populations are of economic interest (Hyman, 1991). In each country of its range, a significant number of wild trees and stands may be located in zones far from human settlements. However, even within the vicinity of villages farmers may not take full advantage of their *Vitellaria* crops. In southern Burkina Faso the comparison of actual yield measurements from a sample of over 50 trees in bush fields and collected amounts as stated by farmers showed that half or less of nut production was harvested (Boffa *et al.*, 1996b). The primary motive for collection was home consumption (of butter). Likewise, only an estimated 5-10 percent of the potential harvest was gathered by villagers in Benin in 1993, despite the fact that *Vitellaria* was the most valued non-timber forest product species in these villages (Schreckenberg, 1996). The discrepancy between production and collection appears to be governed by a complex relationship between labour availability for gathering and/or processing relative to other activities and selling price. The situation is different in Uganda where demand for *V. paradoxa* (ssp. *nilotica*) nuts can exceed supply and collection is very thorough (Masters and Puga, 1994). Prices of *V. paradoxa* products also appear higher in Uganda than in Western Africa.

On the international demand side, European food industries are not concerned about a shortage in supply (Brun, 1996), given that the production potential of *Vitellaria* crops is very large. Never has demand exceeded supply in the history of this crop. Vast areas of *Vitellaria* populations are not being drawn upon for the export market. Several areas with significant resources are becoming accessible through the construction of new roads, including the area of Kayes in Mali, where *V. paradoxa* is believed to originate. Networks of local intermediaries can respond rapidly to increased demand by drawing on nuts which are traditionally stored at the village level. Furthermore, industries are able to store nuts over several years without significant quality decline and thus protect themselves from price increases caused by the large annual fluctuations in supply.

With the possible exception of East Africa, increased production is therefore not a priority in the current situation. Unlike other parkland species, such as *Parkia biglobosa* and *Bombax costatum*, *V. paradoxa* often

main types, 'dark' and 'white' are often distinguished (A.S. Ouédraogo, 1995). At least three varieties of *A. digitata* are recognized depending on bark colour. Leaves and fruit of the black or *zirafin* (Bambara) variety are valued more highly than the red or *zirablé* variety (Maguiragua, 1993, cited in Cissé, 1995). Another grey-bark or *siradjé* variety is mentioned in Sidibé *et al.* (1996). To what extent are these distinctions made in the use and marketing of products and germplasm of parkland species? Generally, the agroforestry germplasm market is imperfect in that no premium is paid for physical or genetic quality and intraspecific diversity tends to be under-appreciated (Simons, 1996).

Potential demand for improved germplasm is also linked to patterns of supply and prices of parkland products, and thus to the density of species available locally. It is not clear, for example, that genetic improvements are necessarily the most effective way of increasing the economic contribution of *V. paradoxa* (Box 4.2). Modelling the likely influence of an increase in supply on prices of products from *V. paradoxa, A. digitata, P. biglobosa* and *B. aethiopum* in western Burkina Faso, ICRAF (1997) found that prices would decline for all products as supplies

occurs in fields at high densities. Thus reliance on a small number of improved trees to meet subsistence and commercial needs could substitute for the maintenance of the more extensive natural stands, which play a fundamental role in maintaining environmental sustainability. Nevertheless, proactive farmer participatory research programmes to identify and propagate elite varieties are far from irrelevant, and could provide an additional incentive for farmers to regenerate this species. The need for an increased supply may also arise with future market developments (see Chapter 7). Domestication research will need to anticipate the consequences that these trends hold for germplasm demand and delivery. There appears to be a need to improve supply regularity, diversify production and cater to the local market of *Vitellaria* fruit (fruit sweetness, high pulp/nut ratio, early or double fruiting, etc.) as well as to the local and international cosmetic market for unsaponifiables.

Another aspect to be considered is the conservation of genetic diversity, both to prevent losses due to genetic erosion related to drought, parasite attack, land clearance or wood harvesting, and for further selection programmes. Trees in the northern range of the species may hold drought resistance characteristics. Additional production traits to be evaluated and selected for include high and consistent tree yield, kernel fat content and quality, agroforestry potential, short juvenile phase, ripening date, resistance to parasitism, etc.

Nevertheless, rather than focusing only on genetic selection, the economic contribution of *Vitellaria* crops can probably best be optimized by the alleviation of key constraints, as identified in recent consultations (FAO, 1998; Savadogo, 1998), through the following activities :

- Promote quality at all production and processing stages by training collectors and processors in appropriate techniques, establishing quality concepts, norms and regulations including an international grading system for butter.
- Create and support an information exchange system (price, supply and demand, etc.) for participants in the *Vitellaria* sector at national, regional and international levels to allow economic operators to better respond to market signals.
- Refine and further develop appropriate, cost-effective extraction technologies with higher extraction yields, lower investment and labour demands, and durable equipment.
- Study and improve packaging options for high-quality and diverse products;
- Promote policies for the local use and diversification of *Vitellaria* products at the national level, as well as local transformation and packaging.
- Target women's groups and support their efficiency and management capacity through enhancing group organization, technical training oriented towards value-added products of consistent and high quality, training in economic and financial profitability concepts and stock management, access to market information and credit, supporting the establishment of revolving funds, and creation of storage infrastructure.

increased, but in different modes according to areas as well as species considered. For instance, the highest and lowest price drops were for *A. digitata* and *P. biglobosa* respectively, and products retained higher prices in areas where the density of corresponding species was lower. This was also the case in a study by Lamien *et al.* (1996) in Burkina Faso. In response to seasonal variation in the price of *V. paradoxa* and *P. biglobosa*, women in Benin maintain their profits by adjusting the weight of sale units or, in the case of processed products, their ingredient concentration (Schreckenberg, 1996). Improvement should thus be spread over a wide range of species and could help farmers distribute their activities according to variations in demand for parkland species. Selection for precocious or double fruiting varieties may be beneficial. Improved storage and processing capacities may also help to counteract the decline of prices resulting from increased supply.

It is important to note that tree management is not uniform throughout given parkland types or species distribution ranges and may vary in intensity depending on a range of conditions. Parkland conservation and expansion efforts including domestication research will be relatively easier in areas where the intensity of indigenous tree management is high or rising. These niches, which are noted in various places in this report, need to be identified more precisely in semi-arid West Africa and targeted for tree improvement activities with farmer participation.

Lastly, little is known about germplasm supply. Domestication can only have an impact if pathways exist to provide farmers with improved germplasm (Simons, 1996). These include distribution (to the National Agricultural Research Systems - NARS, NGOs, communities, the private sector), dissemination (to farmers), and diffusion from farmer to farmer. The demand side including farmers, disseminators and distributors, as well as the supply side, needs to be assessed both quantitatively and qualitatively for parkland species in semi-arid West Africa.

In conclusion, domestication has an important role to play in the maintenance and expansion of agroforestry parklands, but there are wide gaps in the understanding of the needs and types of improved tree germplasm, and its potential impact on the reproduction of these systems. No single method exists to realize its potential immediately. Rather, gradual steps towards the establishment of domestication strategies which are specific to individual tree species, locations and markets are needed. Case studies can serve as models to be adapted to other species. A planting culture driven by demand for subsistence and/or commercial products is necessary for domestication to proceed actively. Research should therefore focus on, and establish, the corresponding links between farmer decision-making processes and conditions of tree resources, as well as characteristics of the demand and markets of parkland products. While increased supply may be central to domestication of scarce, overexploited species, efforts for the improved commercialization of other parkland products may require quality improvements at the production, storage, processing, and packaging stages. Articulate policies for increasing/enhancing the local use of parkland products and organizing and supporting the economic sector based on parkland products would be highly beneficial.

Management and conservation of parkland genetic resources

The concept of forest genetic resources refers to all (environmental, social, economic, cultural, and scientific) values of the heritable materials contained

Fig. 4.13 *Bombax costatum* branches trimmed to harvest the flowers for use in a highly appreciated sauce, with negative consequences for regeneration.
J.-M. Boffa

within and among forest species (Palmberg-Lerche, 1996). The conservation of forest genetic resources aims to guarantee their existence, evolution and availability for future generations. It not only implies preserving the present distribution of natural variation in forest species, but also requires the conservation of processes which promote and maintain their genetic diversity (Namkoong, 1991). Genetic variation in species is essential to their ability to evolve in a changing environment, and is central to tree breeding programmes which aim at further developing tree resources for human needs.

As presented earlier in this report, there are a number of threats, such as drought, land clearing for agriculture, grazing, over-exploitation of wood, fruit extraction, etc., which endanger the sustainability of woody species in arid and semi-arid zones of West Africa. Given the large number of threatened species in these zones and the relatively limited labour and financial resources, national governments and collaborating international organizations see the need to define priority species and populations. For instance, based on the level of threats and socio-economic importance, 11 species were identified for priority conservation at the regional level at an FAO workshop on *in situ* conservation of forest genetic resources in Ouagadougou in 1994 (FAO, 1994). These species, most of which occur in agroforestry parklands, include in alphabetical order: *Acacia nilotica*, *Acacia senegal*, *Adansonia digitata*, *Anogeissus leiocarpus*, *Borassus aethiopum*, *Dalbergia melanoxylon*, *Faidherbia albida*, *Khaya senegalensis*, *Parkia biglobosa*, *Pterocarpus erinaceus* and *Vitellaria paradoxa*. A list of priority species to be conserved at the regional level based on socio-economic and ecological criteria is also regularly evaluated and updated by the FAO panel of experts on forest genetic resources (e.g. FAO, 1997).

The two main strategies for conservation of genetic resources are (i) conservation *in situ*, which involves maintaining the species in its native environment, and (ii) conservation *ex situ*, which implies conservation through seeds, live clones, pollen or tissue. These two approaches are complementary and are used together whenever possible. However, *in situ* conservation is preferred as it is technically and economically more feasible, as well as being based on farmer participation. In addition, it is potentially fully compatible with a continued economic use of forest resources and can contribute to the conservation of associated plant and animal species, and the ecosystems in which target species live.

A wide range of information is needed for successful *in situ* conservation programmes (Box 4.3). Of particular note is the pronounced lack of understanding of the factors which determine the genetic structure of natural populations. The genetic structure of forest populations is generally determined by biological and ecological parameters including distribution area, reproduction system (auto or allogamy, pollination type), seed dispersal, reproduction mode (sexual or asexual), and long-term evolutionary factors including drift, mutation, natural selection and migration (Zongo, 1998). Genetic variation in tree species can be assessed either through the study of phenotypic variation or through molecular and biochemical markers.

Fig. 4.14 *Adansonia digitata* flower visited by a bat. Bats play a significant role in the pollination of several parkland species.
R. Faidutti

Conservation strategies should take into account factors which regulate genetic diversity. It follows that an understanding of these factors is necessary for the development of successful management guidelines and conservation efforts (Chevallier, 1998). In general, trees are known to display a higher genetic diversity than herbaceous plants both at the intraspecific and intrapopulation levels, but a lower diversity at the interpopulation level. Similarly, species with an extended distribution range tend to have a higher intraspecific and intrapopulation diversity but a lower interpopulation variability than endemic species. Wind dispersion of pollen favours similarity between populations, whereas seed dispersion by gravity has the opposite effect. Through the crossing of related or unrelated parents, and depending on the prevailing reproduction system, fruit also contribute to the genetic structure of populations. An excess of crossings between related parents in a random mating system creates more differentiated fruit, and thus populations which are genetically more distinct. This effect can be measured mostly during the establishment of populations, and declines afterwards. There are also annual variations in gene flow through pollen, as flowering density may vary from year to year. In allogamous, wind-dispersed species with a high proportion of genetic variability at the intrapopulation level,

Box 4.3

Basic information needs for in situ *conservation of intraspecific genetic diversity*

Species taxonomy, distribution and genetic structure

- Taxonomy: status of subspecies, taxa, hybridization with related species
- Natural distribution: preferred habitat (topography, soil, geology), geographic distribution, climate range, range reduction or fragmentation
- Genetic variation: between- and within-population variation; morphological variation (seedling morphology; stress, pest and disease tolerance; progeny and provenance trials; biochemical composition), molecular marker studies

Biological characteristics, and ecological processes involved in the evolution and maintenance of genetic variation

- Reproductive biology: mating systems (selfing/outcrossing), pollination mechanisms and pollen flow
- Seed dispersal: agents, patterns and distance
- Regeneration: by seed, coppicing, suckering; ecological succession stage; associated species (competitors, pollinators, seed dispersers, predators, parasites)

Management and utilization information

- Land tenure: institutional types, management practices
- Utilization: intensity and products
- Threats: nature (human, biotic, environmental) and level
- Traditional knowledge: information on varieties and utilization

Source: FAO *et al.*, undated.

conserving a small number of populations will be enough. In contrast, a larger number will be required for autogamous species with high interpopulation diversity.

Like most tropical and temperate species studied so far, parkland species including *F. albida* (Joly, 1991), *P. biglobosa* (A.S. Ouédraogo, 1995), *Tamarindus indica* (Thimmaraju *et al.*, 1977), and probably *V. paradoxa* (Hall *et al.*, 1996) appear to be predominantly outcrossing, with a lower percentage of genetic interpopulation than intrapopulation variation. While phenotypic variation in *P. biglobosa* seeds sampled in five Sahelian countries was higher within than between populations (A.S. Ouédraogo, 1995), interpopulation differentiation in 11 countries measured through electrophoresis was high (Teklehaimanot *et al.*, 1997).

In northern Cameroon, the overlap of flowering periods among *F. albida* trees spread over a period of eight months is favourable to outcrossing (Zeh-Nlo and Joly, 1996). Because pruning extends the flowering period, it appears to favour outcrossing. Pollination could occur regardless of tree height or diameter, since no difference in flowering periods according to size groups was recorded. Therefore, gene flow is not limited among trees of various size classes. Furthermore, although cross-pollination between trees was higher during periods of intense flowering, the outcrossing rate remained high regardless of the density of flowering trees, unlike previous results on other insect-pollinated tree species.

The comparison of two distinct *F. albida* populations in Cameroon illustrates the potential influence of management intensity on genetic diversity (Zeh-Nlo and Joly, 1996). In Zamay, a village with low-intensity agricultural use and marginal pastoral activities, genotypes tend to be irregularly distributed spatially with groups of related trees. In contrast, in Kongola the spatial distribution of genotypes is regular and random with little similarity between neighbouring trees. The situation in the latter village, where cropping and herding activities are widespread, is assumed to result from the role of cattle in seed dispersal over the village lands, thus contributing to the spatial intermixing of genotypes.

These findings suggest that evaluation of genetic diversity should take into account local variations in both time and space. First, maximum genetic diversity will be obtained from seeds produced during the peak flowering season, while seeds produced at the beginning or end of the season may have a narrower genetic base. Secondly, collection schemes should take the spatial organization of genetic diversity into account to ensure better representativeness.

The structure of genetic diversity in *F. albida* at the village level is shaped by the intervention of livestock in tree regeneration as well as farmers' tree selection practices. At the continental scale, it is influenced by livestock transhumant pathways, human migrations, and resource use patterns by wild herbivores. Likewise, flows of *P. biglobosa* plant material across villages, regions and national borders through human migrations, commercial relations and transnational ethnic ties may have contributed to the relatively low phenotypic interpopulation variation observed (A.S. Ouédraogo, 1995).

The impact of practices used in parkland management on processes which influence genetic diversity remains widely unknown and provides numerous opportunities for research. For instance, studying the impact of parkland management practices, including clearing, fallowing, pruning, selective wood harvesting and fruit/seed extraction, would contribute to the identification of criteria and indicators for the conservation and sustainable use of agroforestry parkland systems.

Summary

Farmers have sustained agroforestry parklands through various management practices. Parkland species tend to be regenerated naturally rather than planted. Assisted regeneration can significantly increase tree/shrub densities, either with the objective of reconstituting a parkland cover or for the ongoing production of wood and fodder, especially in areas of high population density and pressure on wood stocks. Tree planting is usually confined to the proximity of homes where tenure is more secure, soils are better fertilized and seedlings are protected from browsing, drought and fire.

With the exception of *Borassus aethiopum*, which is actively planted to compensate for harvesting, planting primarily involves exotic species because of their fast growth rate and the availability of indigenous species in fields and fallows. Increasingly, however, farmers appear to participate in the planting/transplanting and dissemination of local tree species, which can be a useful way of taking advantage of the microsite variability in soil fertility in cultivated fields. Improved fallows, whereby economically useful and fertility-improving trees are planted before cropping is discontinued, appear to be a promising alternative to long natural fallows, but are still at the experimental stage.

Parkland species display some tolerance to fire. Fire may stimulate *Vitellaria* regeneration, but less so than an absence of burning with the removal of plant competition. The beneficial effect of fire protection is more pronounced in drier areas. Frequent burning delays first fruit production in young *Vitellaria* trees, but can stimulate flowering and fruiting in mature trees. However, no evidence points to fire having a role in increasing yields. The timing of fires is a key factor. Late fires are very destructive for growth, wood and fruit production, while burning early in the dry season has little or no effect and is therefore recommended. Several fire control techniques are applied for the protection of valuable trees such as *Parkia biglobosa*. The increase of soil nutrient availability after fire is immediate, superficial and highly subject to loss. While burning is a practical solution to reduce the abundant woody biomass at the end of a fallow cycle, fire control is generally advised in semi-arid West Africa as it contributes to an increased biomass and canopy cover, to the biological recycling of nutrients and to higher system productivity.

Sahelian farmers commonly apply silvicultural techniques to increase production of parkland trees. These include seedling protection and fencing, watering, and the selection of a vigorous shoot, particularly for *Faidherbia albida*. *Parkia biglobosa* is commonly pruned to improve survival and productivity, and for rejuvenation and shade reduction in old trees. Large *Faidherbia* trees are most often pruned for fodder production in silvipastoral zones of the Sahel. Pruning can be intensive (with an average canopy reduction of 40 percent) and stimulates leaf regrowth, causes an additional foliation peak during the rainy season and drastically depresses pod production. Other parkland species are pruned less intensively, often with the objective of improving tree form and enhancing understorey crop performance. Ringing is sometimes carried out to stimulate fruit and seed production. Coppicing and pollarding, practised both in fields and fallows, represent a way of limiting competition with intercrops and providing wood and other tree products in species with good vegetative growth such as *Azadirachta indica* and *Detarium microcarpum*. Parkland trees should be coppiced early in the dry season to minimize competition with crops. Fertilizers are rarely applied to trees, as crops have priority; consequently their effects have been little studied. Techniques including manuring and application of rock

phosphate in conjunction with mycorrhizal inoculation can benefit tree establishment and production.

Available data for various parkland species show that crop productivity under pruned trees is higher than under unpruned trees and sometimes also higher than in open controls. The improved light and soil fertility conditions appear to outweigh below-ground competition which is possibly intensified with root morphology changes resulting from pruning. Pruning appears to hold good potential for improved parkland management, but better understanding of the comparative impact of repeated pruning on soil fertility and crop performance is necessary before recommending it widely. Its effect on the production of fruit, leaf, wood, and other useful products also needs to be quantified to provide a balanced picture.

Organic inputs are necessary to maintain soil fertility in semi-arid West Africa. Preliminary positive results have been achieved with 25-75 kg nitrogen/ha of *Azadirachta indica* or *Acacia lebbek* leaf mulch. Timing of application influences yields in a way related to rainfall distribution and stages of crop development. Highest yields are achieved with mulches combining high nutrient delivery with moisture conservation and temperature reduction. Despite the promising contribution of tree mulch technology, additional research is needed regarding its on-farm application and costs and benefits to farmers. Research is also needed into extending the existing farmer practice of selecting certain crops to take advantage of the specific fertility and microclimate conditions in the sub-canopy ecological niche.

Planting of indigenous trees might be more popular if they had faster growth rates, shorter juvenile phases and higher and more consistent yields. Improving these and other characteristics could take advantage of the great variation existing in parkland species. Guidelines for prioritizing species and characteristics for domestication research have been developed by ICRAF. These indicate that there are certain species of common interest across the Sahel, but also highlight the differences that may exist between social groups. Target groups for domestication must therefore be carefully identified. At the same time as dealing with biological problems, socio-economic and political challenges also need to be overcome. Thus a key to successful domestication of indigenous species and their adoption by farmers is ensuring that demand exists together with a potential supply system to produce and disseminate the improved germplasm. Parkland species which are intensively managed may be the easiest target for domestication. Research with farmers is necessary to identify the levels of improvement required to ensure uptake as well as to make use of their knowledge of intraspecific variation in certain species.

The continued existence of such intraspecific variation is important to allow both natural plant selection and evolution, and the use and breeding of woody plants for diverse, changing needs and environments. Conservation of forest genetic resources requires the preservation of the present distribution of natural variation as well as the processes that promote and maintain their genetic diversity. This can be achieved through *ex situ* conservation of seeds, live clones, pollen or tissue and/or *in situ* conservation of the species in its native environment, as it is practised in agroforestry parklands. The latter is technically and economically more feasible and also preferred because it involves farmers and leaves open the possibility of combining use and conservation of the resource. It does however require a better understanding of the factors that determine the genetic structure of natural populations, specifically their breeding mechanisms. Current research indicates that the majority of parkland species are outcrossing and show a high level of local variation (in both time and space) of genetic diversity.

INSTITUTIONAL FACTORS IN PARKLAND MANAGEMENT

CHAPTER V

Introduction

It has become increasingly clear that improved natural resource management, including the management of agroforestry parklands, cannot be limited to the implementation of improved management and conservation techniques. For management to be successful and sustainable, institutional arrangements, including property and use rights and control and enforcement procedures are needed to ensure that farmers gain from their investment and that benefits to outsiders are controlled and possibly limited (Rochette, 1989; ARD, 1989; Lawry, 1989). The two major categories of institutional arrangements, which clearly affect the way in which villagers manage their natural resources include customary land and tree tenure, and state land and forest law.

Several important studies have raised awareness among forestry professionals of the pre-existing social and institutional systems surrounding forest management practices, and have suggested promising approaches to understanding tenure systems (Bruce, 1989; Freudenberger, 1994). Identifying who holds what tree tenure rights will help project designers avoid the unintended destruction of existing rights, the exclusion of certain groups from project benefits or the capture of the project by an elite for its own purposes (Fortmann, 1985). The study of the various institutions which govern the use of natural resources can also contribute to identifying the types of incentives which capture local interests for improved management. Tenure affects who has access to resources, whether people are willing to participate in project activities, and who benefits from a project.

As a complement to previous chapters which are concerned with a number of biophysical, cultural and economic factors influencing the sustainable management of agroforestry parklands, this chapter explores the ways in which the variety of complex land and tree tenure regimes affect parkland management. Both constraints and opportunities of traditional and legal institutions are reviewed and areas of improvement suggested. It is hoped that this review will enhance the relevance and efficiency of projects tackling the conservation and expansion of parklands, as well as research efforts in this field.

As suggested by Shepherd (1992), the separation of woodland management from management of trees on farmland is artificial because of the continuity between the two in land types, user domains, management practices and management institutions. First, lands alternate between farming and woodland regrowth stages through fallow cycles. Secondly, herders use the forest as a primary resource, while the forest provides important but somewhat secondary resources to crop growers. Finally, both land types are under the single governance of traditional authorities and the failure of state institutions to consider the management of both resources as a single entity has led to many current problems. Consequently, the primary focus of this chapter is on parkland resources, that is, cultivated or fallowed fields, though references to the forest are included when considered useful to capture this continuity.

Traditional tenure of agricultural land

Socio-economic organization and land allocation

Generally speaking, in rural West Africa, a number of extended families (households) including one or more nuclear family groups (one man, his wife or wives and children, or sub-households) reside in patrilineal or matrilineal compounds (see for instance Hammond, 1966; McMillan, 1986). Each household, or in some places, each sub-household represents a production unit corresponding to a group of people who usually work together and share a single cooking pot. The oldest male of each (sub)household is responsible for the nutritional and social needs of the household members, while they in exchange devote a large part of their working time to the cultivation of the household collective fields, the harvest from which feeds the household for most of the year and is under the control of the household head. Individuals (wives, older unmarried children) also have the right to cultivate some land for their private needs, giving

them some autonomy from the household head, who may decide where these private plots are to be located. Crops produced privately are stored and can be used separately from the household granaries. Usually, women do not inherit individual land rights. Plots cultivated by married women and the cash income generated from them will be used to provide the food complements and goods for their own and their children's use. In places, land is also reserved for village community fields which are cultivated by members of each family on a collective basis under the control of the village head. The product is then used for needy families or community needs (McLain, 1990b).

Fig. 5.1 The fibres extracted by these young women from palm petioles will be used to make ropes and baskets.
R. Faidutti

Through membership in a lineage, households inherit land which was first cleared and cultivated by a related ancestor. These rights are transmitted to descendants. The senior elder of the group is responsible for land allocation ensuring that the subsistence needs of the lineage members and their dependants are met equally. When not put into cultivation, allocated land can be 'lost' and its use granted to others by the customary lineage leader.

Modes of access to land

Tenure practices vary locally according to village settlement history and population density, the availability of unfarmed land and the political authority of the chieftaincy. These variations are reflected in the literature. From the various studies available, the following five traditional common avenues of acquiring land have been identified: by first occupancy, by inheritance, by gift, by customary authority and by borrowing. Traditionally, land is not individually appropriated because it is meant for the subsistence of the group and its posterity. However, the frequency of sharecropping arrangements, land rentals, pledging and purchases, especially in peri-urban areas and areas of high land value (orchards) has increased remarkably in the Sahel.

The first kind of land is acquired through the traditional clearing and cultivation of 'bush' or unoccupied and unfarmed land, when such land is still available. The consent of the village headman and the religious leader who often control this type of land is generally necessary before clearing the fields.

The second kind of fields are those which have become associated with a particular household through inheritance from father to son. They are the individual responsibility of the household head and their use and inheritance are not controlled by lineage elders. Women are usually excluded from this kind of inheritance (McLain, 1990b).

Donated land is a category acknowledged by a number of authors (Prudencio, 1983; Sanou, 1986; etc.). It is difficult to document this type of land as it results

from an oral agreement, and is not formally described in the literature; nevertheless it corresponds to a status actually mentioned by farmers. Such gifts are supposedly indefinite, but they may give rise to conflicts with the original landlords. An example may be land granted to set up a compound and surrounding fields, as described by Kohler (1971) in Burkina Faso, which is ceded for as long as the recipient is in residence in that particular area.

The fourth kind of land has been described by Boutillier (1964), Hammond (1966) and McMillan (1980, 1986). The latter calls it land of customary right. It is associated with the positions of clan elders or village chiefs and, unlike lineage land, cannot be inherited. One gains access to it by becoming the eldest member of the clan, in which case it will not be inherited by his son unless the son himself becomes an elder in the lineage. A man may also earn the right to this land when he becomes a village or *quartier* chief. Unless a *quartier* is absorbed into the chieftaincy of another *quartier*, chieftaincy normally passes from father to son and this land thus remains in the same family (McMillan, 1980). These lands of customary right are generally not fully cultivated by the political leaders and therefore constitute a land reserve.

Land of customary right and land acquired both by first occupancy and by inheritance may be redistributed to people outside the original household through a system of institutionalized borrowing, the fifth category. It is not clear whether donated land can be loaned in the same manner.

Land borrowing

There are various reasons why a farmer may need to borrow land. Ancestral land rights are often not evenly distributed among the various inhabitants of a given locality, as the descendants of the first settlers tend to control larger tracts of land than those who came later. As families of a given lineage grow, the division of land among the sons may leave some of them in need of additional farmland. Alternatives for these individuals include borrowing land from other households of the same village, joining the mother's patrilineage in a neighbouring village, resettling some portion of the household in a less populated area or even seeking a source of subsistence abroad, mostly as a plantation labourer in Ghana or Côte d'Ivoire.

Migration has also become a common phenomenon in West Africa. Annual migration to rural areas was estimated to affect 57 000 people between 1969 and 1973 in Burkina Faso (Lewis, 1986). Such a large-scale resettlement process relies on the traditional land borrowing system. Nevertheless, it is not uncommon for some farmers, who have left their home village to cultivate elsewhere, to return once they have gained a greater share of family lands. Some land will have been made available for them because of a change in the subsistence needs and land requirements of the family through migration or death, or because their status has increased. As a result, they have access to land of customary right as described above (McMillan, 1980).

Whether the request to borrow land originates from a member of the extended family, from a villager of another descent group or from a distant migrant, powerful communal moral and spiritual norms dictate that it generally cannot be denied if the site is not currently, or is unlikely to be, cultivated. Swanson (1979) mentions, for example, that land is rarely denied to someone who needs it for subsistence. Should a farmer himself be in need of land, he will rarely force out those borrowing his own land. Instead he will borrow from other kinsmen or non-kinsmen. The

feeling is that "you may be in the same situation of need some day". This explains why a phenomenon of 'landlessness' as such is generally unknown in West Africa. Priority is usually given to kinspeople but loans take place outside clan bonds. In this latter case, they occur within the context of a special relationship such as friendship or intermarriage. Such social bonds appear to be very important for the successful integration of migrant families (McMillan *et al.*, 1990).

Borrowing usually does not involve a direct cash payment as in the Western rent system. Custom requires that small gifts (salt, peanuts, kola nuts, chickens, sheep) or assistance be exchanged for it. They are part of a social security system which allows integration and mutual moral and material support during times of hardship (Prudencio, 1983). These gifts, offered annually, are usually more frequent when borrowers and lenders are not related. However, in areas of high land value, borrowing may be associated with forms of rent payments.

The importance of land borrowing in West Africa has been highlighted in many studies, but its relative magnitude varies according to the land right classification adopted. In nine Mossi provinces in Burkina Faso where population density was above 40 people/km^2, half the cultivated fields were on borrowed land and this proportion increased with population density (Boutillier, 1964). In central Burkina Faso, one-third of the entire farm area was borrowed, while only 5 out of 31 household heads exclusively used land to which they had permanent rights (Kohler, 1971). Similarly, 27 percent of the land under cultivation was borrowed in the eastern part of the country (Swanson, 1979). Saul's research (1988) also yielded a proportion of 25 percent. In the densely populated (55.4 people/km^2) northern part of the Central Plateau, around Kaya, borrowed land area amounted to 56 percent of the total land area planted (McMillan, 1986). Similarly, in Nonghin, Manga area, 16 percent of fields covering 45 percent of the total cultivated area were borrowed (Prudencio, 1983), while in Koin, a Samo village of western Burkina Faso, 40 percent of fields had a borrowed status (Zeeuw, 1997). In the Fifth region of Mali, 40 percent of the landholders interviewed borrow at least one plot of land, and 25 percent farm only borrowed land (McLain, 1992).

Traditional versus state tenure security

Until recently, indigenous tenure regimes were perceived as being unable to ensure agricultural investment and sustainability of land use. Assuming that western models of leasehold and freehold tenure would promote tenure security, agricultural investment, and land markets, colonial and post-colonial administrations generally acted to reduce the influence of customary village authorities regarding landrights in order to achieve resource management based on centralized State control. A concrete step in this direction was the introduction of land titling and registration, which are still thought to be a prerequisite to sustainable land use. It is claimed that the lack of long-term security keeps those who borrow land from investing in improvements, while those who lend it do not allow such investments in order to avoid claims of appropriation by the user. Evidence shows, however, that legal provisions often do not adapt to the local logic and its social and economic dimensions, and do not have expected results. They may run counter to indigenous management systems, trigger resource conflicts and farmer behaviour with positive or negative consequences on natural resource management.

Borrowing is not necessarily an insecure form of land tenure associated with unsustainable agricultural practices. In the Samo village of Koin, in western Burkina Faso, Zeeuw (1997) has shown that borrowing plays a positive role in the

sustainability of land use and does not preclude intensification. As villagers are able to restrict the granting of permanent borrowing rights, overloading the land's carrying capacity may be prevented. In addition, the possibility for farmers to gain temporary access to land results in a flexible, efficient and equitable distribution of land among farming units. Borrowing also contributes to sustainable land use because it gives farmers the option of avoiding keeping a marginal plot in extended cultivation or prematurely taking it out of fallow. Surveys of 150 farms in six villages located in the Sahel, Sahelo-Sudan and Sudano-Guinea zones of Burkina Faso showed that farmers perceive a high degree of security in their land-use rights, except in the case of a relatively small percentage of well defined short-term land loans (Matlon, 1991). Tenure security variables (borrowing versus inheritance; plots located on lineage versus non-lineage land, etc.) had no measurable effect on incentives to invest in land quality improvements such as manuring, fertilization and fallowing.

In Bentenga, many villagers borrowed dry-season vegetable plots from landowners in a neighbouring village, Kaibo, who then used the land for rice and maize production during the rainy season (Saul, 1988). The fact that the land was borrowed did not prevent Bentenga villagers from investing intense labour and cash (in the form of seedlings, fencing and manure) on it. The land grantors concerned thus benefited directly from these improvements for their own cropping enterprises. In Koin, both borrowers and lenders felt that borrowing was not a constraint to the construction of rock bunds (*diguettes filtrantes*), which are one of the most common intensification techniques used locally (Zeeuw, 1997).

Planting trees was generally not allowed by the lender for fear of a permanent land claim by the borrower. Women could, however, plant live fences of trees and shrubs around the plots they had borrowed for vegetable production in order to limit the encroachment of domestic animals. This practice was considered a part of the horticultural production system rather than an act of appropriation. While tree-planting on borrowed land may be limited, trees can still be incorporated in agricultural management through natural tree regeneration, a practice which is not restricted. Being cheaper and more efficient than artificial regeneration in nurseries, this technique is increasingly promoted by foresters (Zeeuw, 1997). Tree tenure is discussed at length in later sections of this chapter.

Legal interventions aimed at strengthening security in indigenous tenure systems may have unpredictable effects. Zeeuw (1997) emphasized that borrowing land is not a simple material agreement but creates reciprocal socio-political obligations between the family of the lender and the borrower. In exchange for the possibility of earning a living for his family, the borrower is expected to observe loyalty to the lender's family. Should formal contracts be legally established to increase tenure security for borrowers, lenders would lose their power to enforce loyalty by recalling their land and would thus be less inclined to lend. Land would, in turn, be distributed less efficiently in villages and used in a less sustainable manner. An important objective of tenure security for villagers is the participation in peaceful and stable social relationships in the village. Supporting the intervention of external legal government authorities to arbitrate in tenure conflicts may thus not be seen by villagers as a satisfactory means of achieving tenure security. Such interventions are only advisable when conflicts cannot be settled within the community.

In Senegal, farmers in Ndam Mor Fademba, showed themselves to be aware that some provisions of the national land laws are not well adapted and, if applied strictly, threaten to reduce the flexibility which characterizes their local system of natural resource management. They have therefore responded in a variety of ways to limit their influence on local systems of resource management (Schoonmaker and Freudenberger, 1992). For example, the 1964 *Loi sur le domaine national* (Law

relating to the National Domain) and the 1972 *Loi relative aux communautés rurales* (Law on Rural Communities) stipulate that all land transactions (land loans are expressly forbidden) must be handled by Rural Community Councils which are entitled to allocate undeveloped land (*terre non mise en valeur*) and to resolve land conflicts. Because the administration has in the past sometimes granted borrowers titles to land they have had in loan for three or more successive years, farmers are careful to limit loan duration, to assess the motives of borrowers, to lend land that is clearly identifiable as theirs by live fences or its central location in their landholding, and to limit the investments borrowers may undertake on the loaned land. Borrowers therefore lose the incentive to conserve and improve lands obtained in this manner.

Furthermore, rural councils may judge lands which are not being used for immediate crop production or for infrastructural improvements as being 'unexploited'. In reality, these fallow lands play a vital role in soil fertility restoration, tree regeneration and forage production, and give essential flexibility to local resource management systems. As a result, farmers demonstrate that they are actively adding value to the land and own it by pruning naturally regenerated trees, by planting *Andropogon* grasses and weeding around them, etc. But they may also engage in more ecologically harmful practices, such as discontinuing fallow rotations, and clearing and planting fields with little or no intention of harvesting the crops (Freudenberger, 1993a). Lastly, village residents attempt to protect their interests by resolving disputes locally following a well-structured consultation process involving the disputing parties, the chief and, if necessary, his council of elders and the whole village. Communities tend to bring conflicts to the attention of rural councils only as a last resort, as these are viewed as corruptible and unlikely to support local concerns. This has strengthened local-level institutions and flexible land-use arrangements which are adapted to local ecological and economic conditions. A similar strengthening of local management institutions resulted from land claims by outside agribusinesses through the Rural Council in the village of Fandène, Senegal, following a plan for the construction of the Cayor Canal (Guèye, 1994). Despite internal land use conflicts, farmers and herders have formed an alliance and developed strategies, including tree planting, to secure their rights over part of the village territory.

There are many other cases when state control of natural resources has had an unfortunate impact on their condition. In Burkina Faso, for example, the 1984 land reform broke with both customary rights and privatization trends by declaring that 'land belongs to the State'. Widely broadcast on the radio, this was wrongly interpreted as permitting open and free access to land reserves. As a result, Mossi migrants who had spontaneously settled in the Volta River Basins were anxious to mark their properties and undertook destructive land clearing and cultivation practices (Pélissier, 1980a; Faure, 1995).

Indigenous institutions regulating the management of parkland resources

Historically, West Africa has seen enforcement of traditional forest management regulations on an impressive scale. Thus felling *F. albida* was strictly prohibited in Sudan, in Niger (CTFT, 1988), in the Baol kingdom of Senegal (CILSS/LTC, 1993b) and in Zambia (Olsen, 1995). In response to the sedentarization of the population and massive land clearing, Tanimoum, Sultan of Damagaram in Niger, established a draconian law for the protection of the environment during his reign from 1854 to

Sahelian rural communities have created an intricate set of rules and conventions including rights, obligations and sanctions regulating access and sustainable use of parklands.

1884. This law listed a number of protected species including *F. albida*, *Balanites aegyptiaca*, *Ziziphus mauritiana*, *Khaya senegalensis*, and *Ficus* spp., and threatened people felling *F. albida*, the most important tree, with the death penalty or amputation of an arm for mutilating it (Sowers and Manzo, 1991). These measures led to a wide expansion of *F. albida* parklands which are still seen today. In a similar way, in the early 1800s, Sékou Amadou, the Fulbe conqueror, established a land-use management system for the inner delta of the Niger and surrounding areas. This system involved the demarcation of cattle corridors in and out of the region, depending on seasonal fodder availability, which are still respected by farmers today (Thomson and Coulibaly, 1995).

Regulating use by outsiders

Villages in West Africa generally have rights to land and other natural resources which are located in a defined geographical area called a *terroir*. However, the degree of control they have over available resources within their *terroirs* varies. Villages can be dominant, semi-dependent and dependent (McLain, 1990b). Dominant villages claim proprietorship over extensive land areas, based on the right of conquest or of first settlement in the area. Over time, villages may have ceded land resources falling within their *terroir* to neighbouring villages. Dominant villages may or may not still exercise control over the ceded territories, making local tenure regimes more intricate. Different villages or *quartiers* may also exercise simultaneous rights over distinct resources (agricultural, grazing and fishing grounds) found in the same land units.

Non-agricultural lands made up of forests, scrublands or grasslands are usually considered as commons and used for pasturing animals or as a source of wild foods and raw materials. Goods derived from trees growing on the bush commons are open to anyone in the village (Thomson, 1983). There may, however, be a theoretical boundary demarcating the respective gathering areas of neighbouring villages.

Traditionally, villages had the right to exclude non-villagers from a number of forest uses such as land clearing, harvesting valuable fruits or cutting valuable tree species (McLain, 1990b). Village control mechanisms were undermined by colonial administrations which issued forest regulations enforced by their repressive police force. The erosion of local resource governance often continued with the implementation of Forest Codes. Much to the dismay of villagers, forest lands are now intensely encroached by outside organized groups of wood collectors for the charcoal and fuelwood supply of cities. Live trees are then cut in great numbers or fires lit to justify dead wood collection retrospectively. When these outsiders do not hold legal permits from the Forestry Administration, villages are sometimes able to prevent their access to the village forests (GRAAP, 1988). Generally speaking, land and forest resources with unrestricted access to residents, neighbours and outsiders are characteristic of land unclaimed by lineages yet often claimed by whole villages, and are more difficult to bring under sustainable management. State devolution of access and use rights to local communities and institutional support seem prerequisites to enhancing the villages' capacities to manage these lands sustainably.

Regulation within communities

In many parts of West Africa, rural communities have created rules and conventions, including rights, obligations and sanctions regulating access to and sustainable use of natural resources. For example, Fischer (1994) provides an analysis of elaborate pre-colonial management strategies for local agricultural,

pastoral and fishing resources In the Middle Senegal River Valley. Similar systems exist for parkland and forest resources, particularly for those of great use and exchange value. These rules are rooted in indigenous knowledge and understanding of the local ecosystem. A wide range of economic, social and religious sanctions reinforces compliance with prohibitions. Collective management disciplines are often enforced by specific religious or political leaders or respected village individuals. By establishing a connection with God and the ancestors, religious sanctions reinforce the authority of current elders and leaders for the management of forest resources. They have meaning for, and have usually been obeyed by, communities.

There exist local institutions for controlling harvest patterns of tree resources. For instance, ceremonies may be held before villagers proceed to harvest tree crops, especially in the case of *V. paradoxa* (Ruyssen, 1957; Pageard, 1971). In Watinoma, Burkina Faso, the earth priests (*tengsoba*) apply the *ganlegre* custom at the start of *Vitellaria* nut maturity, whereby a few *Vitellaria* trees are encircled with baobab strings to signal a temporary prohibition against climbing the tree and harvesting the fruit, and the obligation to leave nuts on the spot after eating abscised fruit only (Vimbamba, 1995). These rules allow equal access among villagers and ensure resource protection and sustainability. Furthermore, commercialization of nuts used to be strongly forbidden. Similarly, in some provinces of the Central Plateau such as Sanmatenga, Ganzourgou and Passoré, a ceremony whereby the chief picked and ate the first ripe pods signalled the opening of the harvest season of *P. biglobosa* pods (A.S. Ouédraogo, 1995). Hagbers and Coulibaly (1989, cited in Lamien *et al.*, 1996) also reported that in Diongolo, the traditional authorities set the date for harvesting *P. biglobosa* pods.

Similar village institutions for restricting seasonal access to economically useful trees such as *Mangifera indica*, *Adansonia digitata*, *P. biglobosa*, *V. paradoxa* and *Cordyla africana*, as well as thatch grasses, fish ponds and drinking-water sources, have recently been studied in The Gambia, Guinea, and among the Mende of Sierra Leone (Freudenberger *et al.*, 1997). These seasonal common property regimes define 'closed' periods when use of resources located on village commons or individually appropriated lands is banned by the village authorities. The various property rights are reactivated after the ban is lifted. These community arrangements are instrumental in ensuring that the harvest takes place after the fruit is mature and that high prices are maintained for the products. They reduce the cost of protecting tree stands with fencing or other forms of control, and minimize potential conflicts between community members in cases of theft. Rule enforcement, consisting of social sanctions which deeply affect a violator's relations to the community and often of heavy fines in money and/or kind, is highly effective.

Other arrangements relate to tree cutting. Seignobos (1996) suggests that interdictions on the cutting of *F. albida* among several ethnic groups in Cameroon may have led people to believe that multiple misfortunes will befall those who cut or use this tree. In the Kumbija zone of Senegal, living trees are usually not cut. The only valid purpose for cutting a live tree is to build the roof of a house, for which purpose *Bombax costatum* is used (Bergeret and Ribot, 1990). In The Gambia, fuelwood is generally not obtained from food trees in order to preserve local tree-based food supplies. Fruit collectors, often women and children, pick only ripe fruit and do so without cutting off branches, leaving the unripe fruit for later collectors. Similarly, traditional regulations exist regarding the number, species and timing of animals to be killed in hunting. Reproduction periods are enforced for the regeneration of forest wildlife (Madge, 1995). In heavily populated areas of northern Nigeria, formal rules governing the felling of farm trees were effectively enforced by the district head up to the 1970s. In Dugurawa, the headman would exhort villagers

to maintain tree stocks for future generations and, rather than requiring formal fees or permits, give his permission for felling trees against the farmer's assurance that they would be replaced by planted or effectively protected seedlings. This system was still evident in 1986 (Cline-Cole *et al.*, 1990).

Rules sometimes apply to all except particular social groups who may be primary users of these resources or who have specific roles in maintaining these arrangements. In Burkina Faso, it was believed that blacksmiths were the only people who would not suffer physical disorders from tree cutting. Similarly, access to sacred groves commonly found within or at the periphery of villages is still limited today and reserved for religious figures. No tree cutting or burning is allowed there (Vimbamba, 1995; Guinko, 1985). In The Gambia, access to the forest or tree cutting by villagers, except specialists such as herbalists, is discouraged by the fact that trees or forested areas are believed to harbour spirits and witches (Madge, 1995).

Collective beliefs deriving from these traditional institutions are challenged by new socio-economic influences and may seem to constrain the development of modern management practices. For instance, taboos may constrain the practice of planting trees. According to Montagne (1986), villagers in Natie (Sikasso area), Mali, do not plant *P. biglobosa* out of respect for taboos. Lahuec (1980) mentions that, not so long ago, the establishment of tree plantations was strongly prohibited among the Mossi and would condemn the planter to certain death. This was also reported for the Banfora region of southwestern Burkina Faso, where Richard (1980) interpreted the taboo as a defence mechanism of traditional land authorities threatened by a modern economic system. Similarly, in The Gambia, a young man was asked by his mother to remove all indigenous tree seedlings in a newly established orchard, including orange and mango trees for fear of bad luck (Madge, 1995). Implicitly, this enterprise might have threatened the political ascendancy of local elders who traditionally obtained their social power and wealth through the sale of oil palm products. It would also challenge the communal tenure rules associated with forest trees.

This should not be construed to mean that planting cannot be pursued in these communities. Rather, such taboos indicate in a powerful way that tree planting on land having some character of common property would threaten elaborate arrangements and diminish the common property rights of others (Shepherd, 1992). Projects should thus look for ways to adapt their objectives to existing indigenous institutions rather than trying to change or circumvent them.

Changing traditions

Not all traditional regulations are still effective in today's environment, and decisions are increasingly made on an individual basis. For instance, an increase in theft is forcing farmers to harvest *P. biglobosa* pods early in order to avoid losing production (A.S. Ouédraogo, 1995). A common action taken by farmers who want to control depredation of their own resources is to make tree ownership more visible to poachers. In Senegal, farmers mark *F. albida* trees with pieces of bark or cloth to discourage Peulh herders from indiscriminately lopping branches from their trees. This method appeared to be successful since it was being adopted by other villages in the area (Seyler, 1993). It is also practised on *P. biglobosa* because of its high subsistence and economic value. In Burkina Faso, farmers place fetishes (*gris-gris*) on or next to *P. biglobosa* trees, as well as spines around the trunk to control theft (Ki, 1994). However, as spines can be removed and fetishes are often no longer respected, individual surveillance is also practised and is the most effective method for protecting pods of *P. biglobosa*.

Authors who have followed the historical evolution of traditional tenure regimes argue that such institutional arrangements are resilient and flexible and show a remarkable continuity across historical periods (Freudenberger *et al.*, 1997). In coastal West African countries including The Gambia, Guinea and Sierra Leone, the existence of seasonal restrictions against picking tree fruit was already documented by Portuguese explorers in the late 1500s. While these methods were traditionally used to regulate access to non-marketed plants, access interdictions were extended to cash crops during the colonial period. Communities used such arrangements to limit the sale of agricultural and tree crop commodities to the international markets when faced with declining prices. Despite colonial efforts to outlaw the practice, these indigenous systems for regulating resource use have adapted to change and persisted to the present day. A determining factor in their continuity has been the fact that they rely on intergenerational cooperation. Elders usually delegate monitoring and enforcement authority to young people and specialized resource users and therefore promote the perpetuation of resource management principles and practices (Freudenberger *et al.*, 1997; Thomson and Coulibaly, 1995).

Fig 5.2 Harvesting of young leaves from a small *Adansonia digitata* tree, Burkina Faso. ***R. Faidutti***

New village-level regulatory processes are being implemented where customary control mechanisms did not exist. For instance, the commercial value of *Detarium microcarpum* fruit, a tree traditionally valued for subsistence, has increased in recent years in Burkina Faso. In Sarogo, heavy exploitation of the species and the resulting absence of regeneration led the village community to appoint a *paysan forestier* (forest monitor) to oversee the conservation of the local *Detarium* forest which had developed on fallows (Wiersum and Slingerland, 1997). Community compliance with harvesting dates and conditions set by the village chief and enforced by the *paysan forestier* is high.

Villages are also anxious to obtain rights to exclude others in order to protect their natural resources. In western Senegal communities are taking collective action against illicit tree cutting for fuelwood and charcoal as well as pruning for fodder (Seyler, 1993). Some have formed '*comités de surveillance*' (monitoring committees), informal groups of household heads who take turns patrolling each other's fields against poachers. Culprits are first verbally warned, and for repeated offences, are referred to the traditional or the forest service authorities. While this measure was fairly successful in areas with low livestock populations, it was more difficult to keep herders or village farmers with large animal herds from pruning trees during dry years. Villages also recruit *paysans forestiers* to enforce tree protection. They are given the power to fine offenders by forest agents and usually receive food aid.

Village communities are taking collective action against illicit tree cutting for fuelwood and charcoal as well as pruning for fodder.

Implications

The above examples show that there is a strong tradition of resource-use regulation within villages. These arrangements are based on a sophisticated understanding that communities have developed of species characteristics and their requirements for regeneration. When the subsistence or commercial value of

parkland resources is high, communities reveal the institutional capacity to maintain, reinforce or construct tenure arrangements and management systems to use those resources in a sustainable way. There is little doubt that such local traditions and capacities are a source of hope for the maintenance of agroforestry parklands in Africa.

These forms of indigenous management are insufficiently studied and understood. More research is needed to better identify their strengths and limitations as well as the conditions which favour their reproduction. Too little is known, for example, about how the enforcement of these property arrangements is sustained in time and space through intervillage coordination, intergenerational cooperation and delegation of enforcement tasks to other village organizations.

Given appropriate recognition by the state, they certainly provide a strong basis for the development of co-management regimes between government and local communities which could be vested with additional powers to regulate local resources (e.g. permits). Because all community members have a part to play in indigenous management institutions, they also provide an entry point for identifying incentives for participation in project activities.

Traditional restrictions, such as those described above, may be the most visible signs of wider indigenous management and knowledge systems which have been responsible for the maintenance of agroforestry parklands. These systems include management practices reviewed earlier, such as the practice of fallow cycles, selective maintenance of preferred species, use of fire, individual tree management techniques, etc. The first answer farmers often give for the justification of parkland agroforestry techniques is that they were born into these systems. The tradition of maintaining and promoting trees in fields is passed from generation to generation and is an inherent part of their cultural and agricultural identity. People also respect their forest environment and associate it with health and abundance. "You will not experience famine if you protect a *kongosirani* (*Sterculia setigera*) in your field" (Bagnoud *et al.*, 1995a). A better understanding of the multiple dimensions involved in these knowledge and management systems would greatly help research and development personnel as well as policy-makers to assist rural communities in further developing and updating sustainable forest resource management systems.

Constraints and opportunities in traditional tree tenure

The previous section examined some of the main features of indigenous institutions governing the management of parkland resources. Nested within these common property management regimes are more specific tenurial practices relating to access to more individual parkland tree resources which are the focus of this section. Unlike Western concepts of tenure in which land and what grows on it commonly form two parts of a single property package, land ownership in West Africa is often seen as separate from ownership of the vegetation on this land. Just as is the case for land, a perception of tenure security is an important prerequisite for intensive tree management. Tree-related rights may be very complex with a number of categories (see Box 5.1) which can be held by different people at different times (Fortmann, 1985). Whereas annual crops generally belong to the cultivator whether he has permanent rights to the land or not, trees, and particularly perennial tree crops, may belong to one person while heritable rights to

the land on which they grow may be held by another person, and yet another person or group may be entitled to gather products from the trees.

McLain (1990a) argues that the primary factor governing rights to plant and use trees is the tenure status of the land on which they are found, specifically whether farmers have permanent or temporary landholding rights. In addition, just as the labour provided in the initial clearing and cultivation of unclaimed land gives a first settler the basis for claiming a proprietary right to a piece of land, tree tenure commonly differs on appropriated and unclaimed land, and for planted versus naturally regenerated trees. Other parameters influencing tree tenure include tree species and their commercial value, tree parts and quantities used, relationships between right holders, etc.

Box 5.1
Categories of rights comprising tree tenure

- The right to own and inherit trees
- The right to plant trees
- The right to use trees
  - harvest fruit, nuts, pods
  - gather bark, fungus, insects, birds' nests
  - use the standing tree: beekeeping or curing hides
  - cut all or part of a living tree
- The right to dispose of trees
  - destroy the tree by uprooting or chopping down individual trees or by clearing a section of the forest
  - lend the use of the tree to someone else
  - lease, mortgage, or pledge the tree
  - give away or sell the tree either together with or separate from the land

(Source: Fortmann, 1985)

Traditional rights to parkland trees on inherited land

In Sahelian villages, under customary tenure rules, rights to trees are usually vested with holders of lineage or inherited land. Landowner control theoretically includes rights to inherit, plant, cut or prune and gather tree products (McLain, 1990b; 1991a). The authority of holders of lineage land may also consist in excluding non-family (and family) members from exercising tree-related rights.

Communities position themselves differently on the continuum from individual to collective rights and the associated restrictions they apply. Permanent landholders in Burkina Faso and Mali generally own *V. paradoxa* nuts in their fields (Ruyssen, 1957; Saul, 1988). The latter author adds that, among the Mossi, anybody can eat *V. paradoxa* fruit (sweet outer pulp) as it perishes very quickly after picking, but that the economically important nut has to be left at the foot of the tree. The permanent landholder may also choose to allow anyone (including land borrowers) to gather the nuts. In contrast, in villages south of Bamako, trees on crop fields belong to the cultivating household, but collection of *V. paradoxa* nuts is carried out by everyone in the village regardless of field ownership (Gakou *et al.*, 1994). A similar pattern was reported among the Bobos of Koutiala, a town in southern Mali, where trees located within or outside cultivated fields would traditionally belong to the community, and landholders could not claim rights to the trees' nut production. Only once the main community collection was completed, was free gathering of the remaining nuts allowed (Ruyssen, 1957).

Property rights become stronger when management tends to be more intensive (Wiersum and Slingerland, 1997). When land is farmed private tree rights mostly predominate, but group rights often reassert themselves when land is under old bush fallow (Shepherd, 1992). There is evidence, for instance, that *Vitellaria* nuts gathered from bush fallow or uncultivated areas are available to anyone on a first-come first-served basis in Mali, Burkina Faso and Ghana, while the nut

Fig. 5.3 Harvesting pods of *Parkia biglobosa*, Benin. *K. Schreckenberg*

harvest from cultivated fields, and sometimes recent fallows, generally belongs to the permanent landholder (Saul, 1988; Ruyssen, 1957; Hall *et al.*, 1996). This relationship between tenure and intensity of management also comes into play in farmers' decision-making, for instance on resource access or conflict resolution as illustrated in the following examples. Schreckenberg (1996) mentions that in the Bassila region of Benin women own the nut harvest of *Vitellaria* trees present in their or their husbands' fields. They therefore prefer to start collecting nuts in bush areas surrounding their fields where competition from other women is greater. Another anecdote from the same area describes two women arguing over the right to harvest *Vitellaria* trees in a fallow area which had been farmed by the husband of one of the women in the previous year. Other village women settled the dispute by deciding that the products of field trees should be reserved for the farmer concerned (and his family) only in currently farmed fields but not in fallows.

Generally, landowners tend to enforce exclusive rights only on tree planting and cutting. Whether exclusive rights to pruning and gathering fruit are enforced depends on the value of the tree species, the type of use, the quantity used and the relationship of the tree user to the landowner (McLain, 1990b; 1991a). Where borrowers are concerned, use rights tend to be less restrictive than planting rights because landowners consider that borrowing farmers contribute to the protection and conservation of trees growing on the land.

In Burkina Faso, Saul (1988) considers the right to harvest *V. paradoxa* nuts to be one of the primary indicators of who maintains permanent rights over borrowed land. In central Mali, borrowers are authorized to a share or all of the wild fruit crops. Permission is theoretically needed for cutting down trees on loaned plots but enforced only for valuable trees. Pruning can be done without the owner's authorization (McLain, 1990b). In M'borine, Senegal, fuelwood collection in the dry season is allowed freely on all villagers' fields and fallows, while only wives may gather from their husband's fields during the wet season. Large branches are reserved for the field owner, regardless of the season (Postma, 1990).

In Yatenga, northern Burkina Faso, deadwood can be collected on any field but the owner's permission is required when live trees are lopped or felled (Thomson, 1980). In the Gourmanche region in the Southeast, harvesting of parkland resources such as *Vitellaria*, *Ficus*, *Tamarindus*, and *Borassus* trees in family landholdings is traditionally open to all in locations of abundant land supply (Swanson, 1979). The only exception is *P. biglobosa* and its widely used and marketed beans, which have traditionally been subject to more exclusive arrangements as indicated by the following examples. In many places, this tree continues to be one of the few non-cultivated trees whose produce belongs permanently to the owner upon whose land it was found. It is a heritable good

which is handed down to the eldest son of the family in some areas of Burkina Faso (Ouédraogo, 1990). In the 1960s, free access to *Parkia* pods was already limited to unclaimed bush land and fallows among the Bobo (Boutillier, 1964). In Bassila, Benin, *Parkia* pods belong to the traditional landowners even in currently uncultivated areas, and a dispute over ownership of a piece of land was settled by finding out who had traditional harvesting rights to *Parkia* pods on the land (Schreckenberg, 1996). Nevertheless, Logba and Otamari migrants often fail to comply with this rule and may instead agree with the landowner to harvest trees and give him a small part of the harvest. Rule enforcement over tree production greatly depends on how close trees are to the landowner's village.

The value of species varies geographically but valuable species are generally those producing fruit for human consumption such as exotic and indigenous fruit trees. In the Fifth Region of Mali, access to less valuable or fallen fruits, or fruit in poor production years as well as dead wood on the ground, tends to be open to all, even to borrowers on loaned land (McLain, 1990b). Increasing population levels and pressure on resources tend to increase their value and contribute to stronger individual claims (Shepherd, 1992). Open-access policy for parkland trees on lineage lands in some places can also shift to exclusion by landholders (Swanson, 1979). While pruning and debarking of *F. albida* is open to all in Dossi, Burkina Faso, farmers' claims to these trees are more restrictive and result in more frequent conflicts with herders in Watinoma, a village with a ten-fold higher population density (Depommier, 1996a). Similarly, as fuelwood becomes increasingly scarce, wood on privately held land will tend to be appropriated less freely. Yet, the relative availability of fuelwood may not be diagnosed properly because this institutional structure remains invisible to the outsider (Hoskins, 1981).

As trees increase in value, tenure rights are more clearly articulated, and the possible dissociation between land and tree rights does not pose management constraints. In Wolokonto, southwestern Burkina Faso, planting of *B. aethiopum* is allowed on plots of land assigned by the village chief. When plots come to be used by other farmers, the *Borassus* palms continue to belong to the original planter. Consequently, the majority of farmers own more trees in other farmers' fields than in their own. Farmers commonly tap palms which do not belong to them but have to give the owner half their earnings from wine sales (Cassou *et al.*, 1997). Similarly, *B. aethiopum* trees in Fandène, Senegal belong to those who planted the trees. Children may be allowed to pick and eat the fruit without permission, but commercial harvesting requires a rental or pledging arrangement with the tree owners (Freudenberger, 1994). Landowners in Bassila, Benin, require compensation for the felling of any oil palm tree for tapping (non-destructive tapping methods are not known in this area). They will visit the area with the tapper and mark the trees to be felled. Payment is per tree or as a lump sum with wine gifts (Schreckenberg, 1996).

Fig. 5.4 Man collecting *Borassus aethiopum* fruit. *R. Faidutti*

Fig. 5.5 Collecting *Borassus aethiopum* sap to make wine. *R. Faidutti*

In the strongly hierarchical Mossi social organization and other places such as northern Ghana, the power of village chiefs sometimes supersedes tenure arrangements governing tree products on lineage lands. *Parkia biglobosa* used to be referred to sometimes as the 'tree of the chief', to whom all or a share of the pod harvest collected by farmers would accrue (Norton, 1988; Boutillier 1964). This custom has somewhat changed with time, but claims of ownership of *Parkia* trees remain. In some places, the kapok tree (*Bombax costatum*) and the tamarind tree (*Tamarindus indica)* are also the Mossi village chief's property (Ouédraogo, 1990).

The fact that in central Mali frequency of tree protection was fairly constant across fields acquired through both inheritance and loans indicates that farmers borrowing land have an incentive to protect some natural tree regeneration (McLain, 1990b). These farmers had the right to prune trees and thus to minimize their interference with crop production and to collect the fruit produced. Despite the meagre comparative data available on tree densities in inherited and borrowed fields, this seems to be the general rule throughout the Sahel. As mentioned above, the contribution of borrowers to field and tree maintenance is recognized. Besides its advantages of low cost, efficiency, technical ease and appropriateness, assisted natural tree regeneration appears to be a suitable technique for promoting parkland enrichment by holders of temporary land rights.

Nevertheless, agroforestry projects focusing on promoting natural regeneration need to assess how such actions may influence the existing tree tenure regime. For example, 16 out of 30 permanent landowners stated without hesitation that, if they were borrowing land, they would not stake out regenerating *F. albida* shoots, as recommended by the Dosso Gao Project (Niger), for fear of having their land reclaimed by the owner. Half the farmers with temporary land rights also expressed concern with respect to being dispossessed for protecting seedlings (Montagne, 1984). Projects, therefore, also need to encourage the definition of clearly articulated rights with holders of both permanent and temporary land rights in order to promote participation across all tenure categories.

Tree planting on borrowed land

The particular tenure status of tree planting (as opposed to protecting natural regeneration) is related to the principle that 'labour creates rights'. Just as clearing a piece of land confers ownership to the clearer, planted trees in Africa generally belong to the planter and tree planting may give that person rights over the land on which they are planted (Fortmann, 1985). While this poses no problem when the planter is also the landowner, planting is sometimes used by people borrowing land as visible evidence of a claim to it. Thus McLain (1990b)

found that, in central Mali, tree planting was relatively more common on donated than on inherited or borrowed land, and interpreted this as a mechanism used by farmers to consolidate their claim to the land. In the Peanut Basin of Senegal, Golan (1990, cited in Seyler, 1993) found that farmers with less secure tenure planted or maintained more trees than farmers with more secure tenure. She concluded that tree planting and better tree management were a way for these farmers to 'prove' their tenure visibly. In contrast, trees which regenerate naturally do not generally modify tenure unless labour is invested for the improvement of tree production. Afraid of losing the possibility of deriving benefits from the land where the trees are established, landowners generally refuse outright to allow borrowers to plant trees on their lineage land (Neef and Heidhues, 1994; McLain, 1990a, 1990b, 1991b; Swanson, 1979).

Because of their limited rights to plant and cut trees, the cultivators of borrowed land tend to be much less eager to participate in agroforestry activities involving tree planting. In fact, in all four areas studied in central Mali, the number of borrowed agricultural plots with planted trees was significantly lower (half or less) than that of inherited plots with planted trees (McLain, 1991a). This also means that people with predominantly borrowed land will be less likely to plant trees than farmers having inherited land only. This is particularly true for certain segments of the population, such as secondary landholders, women, unmarried men, and immigrants who tend to rely on borrowed land to a greater extent than primary landholders.

In Mali farmers are theoretically not allowed to plant trees on borrowed land without securing the landowner's permission (McLain, 1990b, 1991a). Disputes arise when they do so and owners will go so far as to uproot young trees. Borrowers may also be expelled from their holdings when trees are planted (Swanson, 1979; Janodet, 1990). Even when permission is sought, it is most often denied for fear that it will lead to a land claim.

Nevertheless, there are numerous cases of borrowers being allowed to plant trees but the choice of species may be limited. Mango trees, being commercially valuable, were the only trees causing land tenure conflicts in Swanson's research area in Burkina Faso as these (especially the grafted ones) are "the only species considered worth planting and caring for". It is clear that the greater the commercial value of a tree, the stronger the opposition of landowners to allow tree plantations on loaned sites. Authorization to plant trees on borrowed land also occurs in Mali, but exotic fruit tree species such as orange, guava, papaya and lemon trees are excluded (McLain, 1990a). In the German *Projet Agro-Ecologie* in Yatenga, Burkina Faso, experience has shown that efforts to plant the exotic neem (*Azadirachta indica*) on borrowed land often result in the termination of granted cultivation rights. This is not the case for indigenous species (S. Ouédraogo, 1998).

The fact that rights to planted trees may remain ambiguous when owners take back a piece of land can be a disincentive for borrowers to plant trees. However, there are opportunities for landowners and borrowers to reach satisfactory agreements allowing borrowers to benefit from planted trees while safeguarding the owners' claim to the land. Such arrangements are made informally between villagers (McLain, 1991a). In the Bassila area of Benin, farmers who have negotiated authorization with landowners to plant trees in fields, sometimes as boundary markers, choose exotics rather than indigenous species, which could be argued to result from natural regeneration (Schreckenberg, 1996). Species, such as *Eucalyptus* spp., *Gmelina arborea* and *Tectona grandis* are then independently managed, mostly for pole and timber production.

A farmer who returns a borrowed field to the landowner may or may not come back every year to gather products of an indigenous (subsistence) tree species he has planted. He would certainly return, however, if the (exotic) tree produced a sizeable marketable harvest such as mangos. The economic value associated with fruit tree plantations is such that land parcels where orchards are established are more and more being treated as personal property. Unlike most other types of land where the principle of inalienability is respected, plantations are increasingly subject to sales (Saul, 1988).

Commoditization of land and trees

Growing market orientation, in addition to population growth, may tend to dissolve traditional common property systems and individualize agricultural production and land rights (Neef and Heidhues, 1994). This can promote profound changes leading to the individualization of land and labour management strategies. Household members are exerting pressure to free their labour and receive their share of family lands (Ngaido, 1995). In areas of high land value, such as the surroundings of urban centres, shores of lakes allowing dry-season irrigation, fertile low-lying land (*bas-fonds)* in rural areas, orchards, etc., allocation of land in exchange for money is becoming quite common (Freudenberger, 1993a). As agroforestry parkland crops accrue in value, it may be that rights to parkland trees will also become more individualized and strongly articulated, possibly even being used to strengthen rights to land.

In the sub-humid and humid zones of West Africa, tree crop production has led to the commercialization of various rights in trees and land. However, patterns of control over tree crops and their revenues have depended not so much on formal rules of access and transfer but on interactions among potential beneficiaries and their ability to exercise their claims (Berry, 1987). Land transactions in the Sahel are increasingly common whether they take place in opposition to national laws, as in The Gambia where the law protects customary tenure systems, or in accordance with state legislation, as in Burkina Faso where the 1991 *Réorganisation Agraire et Foncière* (Land and Agrarian Reform) officially encourages private property. In reality, producers and private investors, who are allocated traditionally held lands, do not rely on existing administrative and legal frameworks. For example, in Burkina Faso, land titling is not considered as a guarantee for security of tenure by entrepreneurs nor is it recognized by banks as valid collateral to secure loans. Instead such people seek to maintain good relations with local land authorities and rationalize their economic activities by minimizing social risks (Faure, 1995).

Fig 5. 6 A woodworker finishes a traditional mortar used for pounding various foods. Wood for such items often comes from agroforestry parklands. *R. Faidutti*

Rather than 'private property', access to tree crops can better be described as 'a degree of individual control'. A number of pathways including inheritance, labour investment, and migration create multiple overlapping rights to tree crops so that control patterns remain subject to re-

negotiation and redefinition (Berry, 1987). Over time the evolution towards the commercialization of rural assets in agroforestry parklands may follow similar trends and should indeed be allowed to proceed endogenously.

Women's rights

Because women usually marry outside their native villages and patrilineal kinship controls land allocation, they have to borrow land from their husband or their husband's relatives. The location of allocated land may change from one season to the next (Matlon, 1991; Postma, 1990), but this varies geographically. In some places in Burkina Faso and Senegal, women sow Bambara groundnut or fonio (*Digitaria exilis*) plots after the major planting of millet and sorghum, generally on residual unplanted field portions. They often do not know at the outset of the season where their major plantings will be located, nor at the end of the season whether they will be able to cultivate the same plot the following year (Matlon, 1991). In contrast, land allocated to a married woman by the head of the family in Ndam Mor Fademba, Senegal, is stable and securely held for as long as she stays in the family (Schoonmaker and Freudenberger, 1992).

Trees located on women's fields generally belong to the men lending the piece of land who may, however, concede to the women the right of access to them. In central Mali, women have the right to trim branches and gather fruit and dead wood without permission from the landowner. Women are also usually responsible for the processing and commercialization of parkland products (see Chapter 7). Tree protection is not less common in women's than in men's fields in central Mali (McLain, 1991a). Densities of self sown trees were even found to be significantly higher in women's fields (35 trees/ha) than in the fields of household heads (24 trees/ha) in Thiougou, southern Burkina Faso, where women had long-term land loans (Boffa, 1995). Various vegetables and spices as well as some cereals are grown in women's fields, whereas family fields are more exclusively oriented towards staple cereal production. With fields of similar species richness but about three times smaller than those of family heads, the number of tree species per unit area was twice as high in women's fields as in family fields managed by male household heads.

Fig 5.7 Women bringing home fuelwood.
R. Faidutti

These overall and specific density differences show women's particular interest in maintaining a significant production of various crop and tree products in their fields, and this was not constrained by the local tree tenure regime. It has been reported, however that when products such as *Vitellaria* nuts have increased value as a cash crop, men have reduced women's access to this resource (Snoy in Crélerot, 1995; Khouw and Golane, 1987). A similar trend resulting from the introduction of domesticated material or improved processing technologies might develop to the detriment of women, and changes in tree tenure therefore need to be monitored, and consequences anticipated.

There are also examples of finer scales of rights regulations within gender groups. These confirm the continuity of tenure rights from the most to the least 'visible' as well as their pervasiveness. In polygamous marriages in Ghana, the oldest wife regulates access of household members to *Vitellaria* nuts (Pugansoa and Amuah, 1991). In Bassila, Benin, *Vitellaria* trees close to villages are generally harvested by the older village women. Women explained that this is in part because older women get up early in the morning to harvest these trees before anyone else, but also because younger women deliberately leave these more accessible trees for elderly and incapacitated women (Schreckenberg, 1996).

Women can theoretically plant trees on borrowed land but they are discouraged from doing so because trees revert to the owner when the loan is discontinued. Unlike men who may use tree planting as a means of gaining control over borrowed land, this is not an option for women (McLain, 1990b). Some married women in Bassila villages in Benin choose to plant trees next to their parents' compound rather than their husband's in order to avoid the risk of losing them if their marriage breaks down (Schreckenberg, 1996). Thus, the lack of tenure security for women is a disincentive to long-term investments such as tree planting. The number of women having planted trees was in fact significantly lower than that of men in Malian villages. A large percentage of women being secondary holders, they tend to have fewer rights to trees than primary holders (McLain, 1991a). There may also be cultural constraints to women participating in tree-planting operations. In Petit Samba, Burkina Faso, planting is never done by women (Gijsbers *et al.*, 1994).

Current trends including permanent cash cropping, plough farming and population increase, which cause a reduction in fallow area and duration, tend to have a negative effect on women's production and tenure of two primary forest resources: fuelwood and *Vitellaria* nuts (Grigsby and Force, 1993). Fallow reduction requires greater labour for fuelwood collection, and restricted access to both resources because land tenure, which is communal during the fallow phase, becomes more individualized or kin-based during the farming phase. Furthermore, while formal credit may be a necessary step for women to adopt efficient forest-related technologies, insecurity of access to land resources currently makes this investment too risky. The involvement of social organizations such as women's groups may be a way of increasing their access to land resources and making credit more affordable and labour more efficient.

A number of cases suggest that women's land and tree rights and living conditions are more vulnerable to land use changes, than those of male landholders.

In Senegal, vegetable gardening in bottomlands has expanded significantly in recent years. Because these areas were traditionally used primarily by women and children to collect non-timber forest products (fuelwood and fruit), their conversion into vegetable gardens may have a negative impact on women's ability to supply household needs for forest products and may place increased pressure on parkland trees (Seyler, 1993). Moreover, much of the collected fruit is sold on local markets and represents a significant income for women. In contrast, income from vegetable gardens is for the men of the household. Zeeuw (1997) also contends that women can be more vulnerable to conflicts affecting land tenure security. In Koin, Burkina Faso, women borrow land to establish vegetable gardens which they may lose in case of conflicts. Because they often make permanent investments (fences, well, etc.) and the gardens are generally located on village fields, that are more scarce and less easily replaced than bush fields, they stand the chance of losing more than men in such conflicts.

There may also be gender conflicts regarding management, access and control over parkland tree resources. For instance, men usually control *P. biglobosa* fruit while women are the beneficiaries of *V. paradoxa*. In villages where intensification of

agricultural land use is in progress, farmers have tended to reduce tree densities in recent years (see Chapter 2). In order to arrive at densities they consider more optimal, male household heads may cut down *V. paradoxa* trees. This is opposed by their wives who share the labour on family fields. Consequently, men have to maintain sufficient *Vitellaria* densities to satisfy them (Bagnoud *et al.*, 1995a; Schreckenberg, 1996). The fact that income from parkland trees is divided among several household members can be a constraint, since the profitability of tree conservation is not perceived at the global farm level (Bagnoud *et al.*, 1995a). In Benin, women also complained that men do not pay sufficient attention to the development phases of *Vitellaria* in deciding when to burn their fields (Schreckenberg, 1996), even though fire may be detrimental during flowering or fruiting. Bobo women in Burkina Faso have also been observed to plant *P. biglobosa* trees in their husbands' fields secretly because they are entitled to half the production (Ki, 1994). As Hall *et al.* (1997) noted, the secret character of this operation and the social risk involved demonstrate the significance of gender differences over tree management strategies and the importance of these tree resources.

Implications of traditional tenure regimes

Traditional tenure regimes are an important driving force of individual and community decisions about land use and trees in the Sahel and Sudan zone of West Africa.

There appear to be no major tenure-related obstacles to tree-planting activities where farmers have permanent landholding rights. In contrast, parkland enrichment through planting on borrowed land is likely to face strong resistance and create great conflict with traditional landowners. But the conditions surrounding tree planting are likely to be very site-specific and need to be analysed on a case-by-case basis to increase the success of forestry development efforts. For instance, in areas where loans can be inherited if not reclaimed after a generation, second-generation settlers should be able to participate.

A number of strategies have been suggested to increase participation of land borrowers in tree planting activities (Freudenberger, 1996; McLain, 1990b, Raintree, 1987). Official oral or written agreements between borrower and owner can be negotiated to guarantee benefits to the borrower from trees planted while keeping intact the landowner's permanent land rights. Such contracts may even be necessary when the landowner authorizes tree planting so that litigation is avoided once trees mature to a productive age. Another possibility is to encourage landowners to require tenants to plant trees in return for a contractual share of the harvest. Finally, it is important to recognize that not all trees have the same importance in the eyes of the landowner, and it may be better to encourage the protection and planting of indigenous parkland species rather than introduced fruit trees. For some purposes, shrubs may fulfil a land borrower's needs and be acceptable to the landowner. Overall, it seems that landholding status has little effect on incentives to protect natural tree regeneration in parklands. This characteristic as well as technical and cost advantages argue strongly in favour of this technique as opposed to tree planting for increasing tree densities in parklands.

Women may be most disadvantaged by indigenous tenure rules, as their access to land is often temporary and is a disincentive to investments yielding benefits in the long term. Parkland agroforestry activities should attempt to help women negotiate agreements with landowners to allow tree planting. They could also focus on promoting technologies which require minimal labour and capital investments to produce rapid returns, and on increasing opportunities involving parkland tree products.

Impact of State policy on parkland management

Traditional tenure regimes are an important driving force of individual and community decisions about land use and trees in the Sahel and Sudan zones of West Africa. Since colonial times, a system of national policies and rules has also been superimposed on the local organization of forest resource use and management. The concentration of decision-making power in the state contrasts markedly with indigenous tenure systems which usually offer individuals and groups extensive control over tree and forest management. Traditionally, permanent landholders own and can harvest trees on their own land. In contrast, the state considers these resources to be public goods and requires permission and often payment for their use. While traditional institutions may restrict the harvesting and cutting of some valued trees, even when located in farmers' fields, the tree owners nevertheless retain considerable control and there is no barrier to the use of dead trees, or the lopping and pruning of live trees. The converse is true of state regulations which have tended to be much more restrictive even on farmers' own land, and have therefore been opposed by most farmers. The large body of literature on Sahelian land and tree tenure suggests that the claims of the State over forest resources are a much greater constraint to the improved management of agroforestry parklands and forests in general than are indigenous tenure regimes.

Based on available studies of the management of on-farm trees and agroforestry parklands, the remainder of this chapter highlights some of the characteristics, ambiguities and weaknesses of Sahelian forest codes, focusing primarily on Senegal, Mali, Burkina Faso and Niger. Wherever possible, information on recent forestry legislation is provided, but as little is yet known about how this new generation of forest laws will be implemented, observations based on the application of earlier laws are also included.

Forestry legislation in the Sahel

A great deal in the forest codes of independent French-speaking Sahelian countries is derived from colonial land and tree legislation, which emphasized state control over land resources and took little account of traditional individual and community rights to land, trees and forests. Colonial administrative texts applied to the whole of French West Africa, which included present-day Benin, Guinea-Conakry, Burkina Faso, Côte d'Ivoire, Mauritania, Niger, Senegal and Mali. Among major texts, the decree of 15 November 1935 declared as state property any 'vacant land without master', including all land unoccupied or unexploited for more than ten years. By offering the possibility of registering land through the establishment of land titles (*livrets administratifs*), the decree of 20 May 1955 officially acknowledged collective or individual customary rights. However, because land registration in the Sahel is generally a costly and lengthy process, registration of rural land has been limited. The state has thus maintained a monopoly on the majority of rural lands. As a result of the decree of 4 July 1935, the state was also given the authority to manage and regulate use of all forest resources in French West Africa. Concerned about apparent environmental degradation throughout the region, forest management policy emphasized regulation and enforcement and consisted largely of lists of restrictions on forest use applied through a system of permits and fines (CILSS/LTC, 1993a, 1993b).

Sahelian forest codes have generally distinguished between a forest domain (including the classified and the protected forest domains) and the non-forest domain (including cultivated and short-fallow land, registered land and urban land). Classified forests belong exclusively to the state domain while protected forests do not. The purpose of classified forests is to set up permanent forests with designated uses (forest production, protection, botanical or wildlife sanctuaries, etc.). Their access is more restricted than in protected forests where customary use rights may be authorized (in a regulated manner) unless they are excessively destructive. Furthermore, whether it is explicit as in Senegal or implicit as in Mali, state jurisdiction extends beyond the forest domain and regulates the use and harvesting of trees on cultivated and fallow areas, which constitute the typical zone of agroforestry parklands (Elbow and Rochegude, 1990).

Use rights in the forest domain vary slightly in each country, but have the same basic characteristics. Commercial tree harvesting is generally taxed, while this is usually not the case for the collection of fruit, honey, medicines and other non-wood items. Cutting wood for domestic purposes requires a permit (often free of charge) from the forest service. The forest service can also issue woodcutting permits for areas traditionally controlled by local communities without consulting them, which reduces their ability to exclude outsiders from exploiting what they consider to be their traditional forest. Separate permits are required for the transportation and storage of forest products. All national forest laws also prohibit the unauthorized felling, lopping, pruning, mutilation or use of a list of economically significant species. In fact, most of these species are already protected under traditional management systems. Debranching for animal forage is allowed in restricted conditions. A permit is sometimes needed for clearing of land for agricultural production.

Sahelian codes give forest agents broad police powers to pursue suspected violators. They are allowed to bear arms and seek the help of public forces for enforcement. They may confiscate illegally gained forest products as well as vehicles and tools used for their collection and transportation. Further penalties are specified in detail in the legislative texts.

However, starting in the late 1980s, Sahelian countries have moved towards the inclusion of rural populations in the management and protection of forest resources. Policy dialogue has been actively encouraged by the CILSS (Permanent Interstate Committee for Drought Control in the Sahel) and the *Club du Sahel* which were created soon after the intense droughts of the early 1970s. By sponsoring research studies, circulating information, and organizing regional, sub-regional and national workshops, among the most significant of which were the Nouakchott (1984), Ségou (1989) and Praia (1994) international conferences, the CILSS and Club du Sahel have increasingly emphasized the need for local control over natural resources. Forest services and donor agencies have designed new forestry laws which devolve various degrees of rights and responsibilities to local communities. New forest laws were decreed in 1997 in Burkina Faso (Burkina Faso, 1997), in 1995 in Mali (République du Mali, 1995) and in 1993 (legislative section) and 1995 (regulatory section) in Senegal (République du Sénégal, 1993, 1995). In Niger, legislation relating to the Rural Code (République du Niger, 1993) is currently being revised. The implications of these legislative changes for local participation in parkland and forest management are analysed in later sections.

Ambiguities in forest codes

A key constraint to the management of agroforestry parklands is the fact that, before the recent revisions, Sahelian forest codes often failed to define the rights

of individuals and communities to forest resources in the non-forest domain. The Malian forest code, for example, did not specify clearly whether (commercial or non-commercial) use and transportation permits were required for trees outside the state forest domain. Nor did it specify whether harvesting products from protected species for domestic purposes needed authorization (and at what cost), or whether restrictions on the cutting, pruning and use of protected species applied to the non-forest domain. The absence of provisions, such as the criteria for granting or refusing free permits, left many decisions to the discretion of the agents whose tendency was to restrict rather than increase access.

The extent to which the status of lands and trees in agroforestry parklands has been make clearer in recent forest legislation varies by country.

Farmland technically falls outside the forest domain, yet the fact that rural landholdings, being mostly unregistered, fall under the state's claim aggravates these ambiguities. While codes may have intended to apply different rules on farmland than in the forest, foresters have tended to extend regulations for the protected forests to all unregistered land including forest resources on cultivated land.

The extent to which the status of lands and trees in agroforestry parklands has been made clearer in recent forest legislation varies by country. Burkina Faso's new code stipulates that 'areas covered with tree or shrub communities resulting from agricultural activities' are excluded in the definition of forest to which the forest code applies (Burkina Faso, 1997). This implies that the Burkinabe state claims no control over forest resources in agroforestry parklands. Furthermore, the provision stating that all forest land, except private and state classified forests, constitutes the forest domain of local collectives, excludes direct state control of agroforestry parkland zones.

In contrast, forests are rather loosely defined in Senegal, Mali and Niger as lands whose exclusive or main products include any timber and non-timber forest/tree products. More specifically, the 1995 Senegalese law includes 'cleared lands previously covered with trees where tree regeneration or planting will be allowed', and 'cultivated lands assigned by owners to forestry activities' in its definition of forest. This would apparently mean that parklands as tree communities in fields and fallows are subject to forest regulations. Similarly, *les terres à vocation forestière, boisées ou non* (lands with a forestry potential whether wooded or not) are considered part of the national forest domain in Mali.

Inappropriate rules

In addition to the inherent ambiguities outlined above, Sahelian forest codes are the source of many inappropriate rules and regulations. These are often hard to enforce and do not reflect local realities, resulting in outcomes which run counter to the original intentions of achieving sound management of the country's forest resources.

Based on McLain's study (1992) in Mali, this section focuses on specific regulations which may lead to ineffective parkland management and outlines relevant changes in recent forest laws.

Insisting on free permits for cutting and pruning parkland trees or for transporting tree products is fruitless in a situation in which forest services do not have the capacity to deliver free permits on the necessary scale (McLain, 1992). The experience of the CARE project in Koro and Djenne, Mali, shows that even with substantial external assistance, the forest service cannot adequately administer a system of free permits for field trees. Furthermore, the insistence on permits, free

or otherwise, is a disincentive to local participation in parkland management as it prevents farmers from practising the tree pruning and thinning necessary to optimize both tree and crop production.

As mentioned earlier, the new Burkina Faso forest code appears to have alleviated such constraints. Besides the exclusion of farmland from the forest domain, forest use rights for subsistence purposes are allowed free of charge and without prior authorization (Burkina Faso, 1997). Uses include the collection of dead wood, fruit and medicinal plants in classified forests, and cropping, grazing, and forest product collection in protected forests. Felling trees in the forest for commercial purposes is subject to a permit and tax, but it is allowed on continuously cultivated fields. A list of protected species is determined by ministerial decree.

In Mali, use rights in forests protected by the state or decentralized territorial collectives include grazing, cutting of forage, collection of dead wood and forest products. But in both forest types, cutting of live wood first needs to be authorized by the forest service (République du Mali, 1995). A permit is also required to fell or uproot any of 11 protected trees, most of which are common parkland species. In addition, local collectives are themselves allowed to protect all species in need of conservation. Because farmland is not clearly excluded from the forest domain, these provisions suggest that pruning and felling of field trees still require a permit and that prohibitions relating to a range of parkland species continue to hold. Little seems to have changed, therefore, in terms of farmer access to parkland trees. The transfer of fallow lands into the state domain after five years has now been extended to ten years, which may reduce the lack of farmer incentive to protect tree regeneration and manage lands on the long-term scale necessary for the restoration of soil fertility.

In Niger, the Rural Code recognizes customary authority as a way of obtaining effective land tenure (République du Niger, 1993). The texts stipulate that any natural or artificial component of agricultural lands, such as trees, belong to the landowner. All customary use rights are maintained in the protected forest domain, while in classified forests, cropping is prohibited and only deadwood and other non-wood forest products can be freely harvested, even for commercial purposes. However, unauthorized felling or uprooting of a number of protected species are forbidden outside urban areas, vegetable gardens and orchards. Debranching is prohibited in classified forests, and pruning of 'small' branches is allowed in protected forests only when practised 'correctly'. Parkland management practices are thus largely restricted by these provisions. Fallowing is another important practice which may be adversely affected by the possibility that agricultural lands can be transferred to a third party after three years of absence or 'insufficient development'.

The new forest code in Senegal seeks both to encourage local participation and to ensure forest resource protection and restoration. It claims to be innovative in increasing rights to private, physical or moral entities who invest in land improvements, and in introducing the need for prior declarations to the forest service as a way of preventing populations from suffering penalties attributable to the administration's inefficiencies. The 4 February 1993 law states that any collection, cutting, transport and processing of forest products (fruit, gums, resins, honey, etc.) by people holding ownership, usufruct or contractual rights to forests must be authorized by the forest service (République du Sénégal, 1993). Neighbouring communities are allowed to enter national domain forests to collect dead wood, straw and forest products, practise limited grazing, prune and debranch fodder species, and harvest wood for construction and repair of houses. Commercial harvesting is taxed and requires a harvesting permit.

Various additional clauses appear to centralize control over virtually all parkland trees in Senegal through the obligation to declare or obtain authorization for exploitation activities. The code states that plantations are the private property of the planter, but the land on which they stand remains part of the national domain. Furthermore, although harvesting of forest products from private plantations is free, it must first be declared to the forest service, which should then issue a free permit within eight days stating any conditions (République du Sénégal, 1995). The code also presents a list of 11 completely protected species which cannot be felled, uprooted, mutilated or debranched except with prior permission from the forest service for scientific and medicinal purposes. Another set of 14 partly protected species cannot be felled or mutilated without authorization, and the same applies to any isolated woody plants in agricultural lands, playing a role in fertility and sustainability. In addition, tapping of *Elaeis guineensis* and *Borassus aethiopum* is strictly prohibited in the national domain. Felling, debarking and debranching of trees outside residential compounds (*concessions*) requires authorization. Taxes are applied when these operations have a commercial purpose. Forest products cannot be transported without a permit, which is delivered free of charge upon presentation of the harvesting permit. Finally, land clearing is subject to a heavy authorization process, which takes up to five months and requires the payment of a tree cutting tax prior to approval. While these control or declaration procedures may be seen as a way of alleviating negative consequences for populations (République du Sénégal, 1993), they also have hidden costs for rural residents (see below), and maintain state control over access to and management of parkland resources.

Institutional structure

The emphasis on repression rather than extension as well as the misapplication of forest laws, appears to be accentuated by the financial structure of fines. As a result, forest agents are feared and mistrusted, and often viewed as the most corrupt and repressive of state agents by farmers. In Mali, revenues from collected fines are distributed as follows:

- 10 percent to the person who reports the offence (in practice always the forestry agent),
- 5 percent to the agent who writes it up,
- 10 percent to management levels of the regional forestry service, and
- 75 percent to the Forestry Fund (Shaikh, 1986).

Kerkhof (1990) indicates that fines are essential to agents' livelihoods, given their low wages which are also often paid three to six months late, and the lack of support for operational expenses. The natural consequence of this incentive structure is that enforcement work is favoured over activities which do not supplement a forest officer's income, such as extension education. Farmers report being arbitrarily refused free authorizations, while agents deliver permits to those willing to pay for them with no regard to environmental consequences. Farmers also suspect that forest agents do not report the fines and keep the revenues collected. Less than 20 percent of offenders in Mali received a receipt for the fine they paid (McLain, 1991a). Departure from forest laws by agents themselves further reinforces the feeling that these permits and fines are taxes and penalties rather than incentives to adopt more sustainable practices (Sanogo, 1990). No incentive exists in the structure for field agents to monitor one another. Finally, farmers feel that they cannot protect themselves against misapplication of the

regulations. The high cost and complexity of procedures for contesting fines have prevented the development of effective mechanisms to check abusive fining.

The traditional emphasis in foresters' work on law enforcement has contributed to a negative attitude of forest agents towards the capacity of local communities to regulate the use of forest resources. In the Fifth Region of Mali, agents generally believed that neither farmers nor herders could be trusted to manage and protect trees in parklands and forests, and that a withdrawal of the forest service would lead to forest destruction (McLain, 1992). In contrast, farmers believed that they have a vested interest in protecting village tree resources, and there are many indications that they would manage their tree stock more actively in the absence of regulations as currently enforced. In places farmers feel that they can enforce resource protection at the village level while others recognize that seasonal migration and labour demands for agriculture make it more difficult. Their capacity to control forest resources has however been undermined by the state which issues cutting permits without consulting villages on appropriate species and locations, and most are clearly aware that in order to control their forest resources they need the state to devolve the authority to enforce local rules. A new emphasis on advice and extension in Sahelian forest services, including training in the improvement of indigenous forest management practices, would contribute to a gradual change in foresters' evaluation of local decision-making capabilities.

Farmers' perceptions of their rights

The literature suggests that farmers perceive their rights to access and manage trees in their agricultural holdings to be strictly limited by the state. In Mali, for instance, over 90 percent of villagers interviewed in the Fifth Region thought that they risked a fine for pruning trees in their compounds and fields (McLain, 1991a). Most people tend to presume all cutting activities are illegal regardless of tree species, regeneration method and location (McLain, 1990).

The poor understanding of forest laws by rural residents is the result of low literacy rates, the lack of translations of forest codes into local languages, and the ineffective and often biased extension efforts of forest agents. Because forest

Box 5. 2
At what cost a permit?

Observers in Mali, Cameroon and elsewhere note that the cost of permits for commercial (wood and gum) harvesting in addition to the expenses required to secure them are excessive and do not make the enterprise worthwhile to individual farmers (Bagnoud *et al.*, 1995a; Bernard, 1996). Permit rates are not in line with the prices of the products they yield, including fuelwood, which is usually not limited locally, and furniture making, for which boles of parkland trees are generally too short. Thus instead of raising the value of trees, permits represent a constraint to the economic optimization of the agricultural system to which farmers respond by adopting a passive or even negative approach to tree management.

Most individuals take the risk of being fined rather than purchasing a felling permit because they say permits are too expensive and not enough wood is collected to justify it, or because it is often not worth the time and travel to understaffed forest service offices. Only people whose activities are visible to forest agents tend to buy felling licences. Such people are often organized in group associations through which they acquire collective permits (McLain, 1990b). Fines do not vary according to amounts of wood harvested so there is little incentive to limit illegal cutting.

agents themselves often do not know the code well, regulations may be applied inappropriately or simplified, usually in favour of the agent or the state. Thus the majority of forest agents in Mali required farmers to get a permit to prune or cut any parkland tree and a large percentage of them required farmers to pay a tax for felling trees, even in their own fields. Similarly, lopping restrictions were turned into prohibitions by several agents.

Their perceived lack of rights has had a negative impact on farmers' ability to manage their trees in an optimal manner and has even led to counterproductive practices. In a study on tree pruning in Burkina Faso, Timmer *et al.* (1996) found that the fear of forestry agents, who fine farmers for any intervention other than fruit harvesting and collection of dead wood, is the primary reason why farmers do not prune parkland trees to a greater extent. Farmers' inability to cut off branches of *Vitellaria paradoxa* infected with *Tapinanthus* parasites, because of the tree's protection by the Malian Forest Code, was held partly responsible for the high percentage of infected trees (Yossi and Traoré, 1987). While regulations allow woody shoots to be cut during land clearing, they prohibit the felling of a tree. This is detrimental to the practice of coppicing, traditionally applied by farmers to species such as *Detarium microcarpum* (Wiersum and Slingerland, 1997). It also prevents farmers from disposing of unproductive trees on their farms. Even old and dead *V. paradoxa* and *Parkia biglobosa* trees cannot be felled without a permit (Bagnoud *et al.*, 1995a). In Senegal, farmers complained that they needed a permit from the *Département des eaux et forêts* to harvest the relatively high number of *Faidherbia albida* trees in their fields which had died as a result of a drought (Seyler, 1993).

Furthermore, because of the way regulations are applied, farmers have little interest in planting or protecting too many trees, as restrictions forbid farmers to thin or prune them. As a result, seedlings which have naturally regenerated are deliberately ploughed under or browsed by animals before they become too visible to the forest agent (McLain, 1992). Other consequences include the inaction of farmers in response to heavy infestation of plant parasites on *V. paradoxa* and several other parkland species, and the foregoing of significant benefits related to improved parkland management, such as higher crop productivity due to reduced tree competition with crops, tree rejuvenation, longer life expectancy and increased fruit production, reduced bird depredation, reduced weed growth, etc. In brief, perceiving a lack of rights to carry out most tree management practices, even ecologically sound ones, farmers have managed their agroforestry parklands in less than optimal ways.

The neglect of pastoral practices in land policies

Despite the major importance of forests for pastoralism in the Sahel, the management of grazing and browsing resources constitutes only a minor part of national legal provisions. Herders' access to forest resources is somewhat less restricted in the new regulations of some countries, but legislative reforms are still timid in view of the specific resource management needs of pastoralists. Before 1995, grazing in Mali was prohibited in classified forests, tree felling was strictly forbidden in the Sahelian zone, and although branches above 1.5 m could be cut (Elbow and Rochegude, 1990), this was often interpreted as a total ban on debranching (McLain, 1992). Cutting of fodder is now allowed in the state protected forest domain, as well as in the forest domain of local collectives which have to put forward 'appropriate protection and conservation measures' (République du Mali, 1995). Because they are given the right to approve the forest management plan established by the forest service, local communities may have a greater opportunity to include measures for the management of pastoral resources.

Few specific provisions on grazing rights in forests exist in Niger (République du Niger, 1993). Customary access is allowed in protected forests as is lopping of small branches. In classified forests, the introduction of livestock can be forbidden if deemed detrimental, and lopping of branches is illegal. In Burkina Faso, grazing rights are permitted in forests held by local communities (i.e. all forests except classified state forests and private forests). Other use rights may be allowed if specified in the management plan (Burkina Faso, 1997). Forest exploitation by communities is expected to contribute to the sustainable management of all agricultural, pastoral and forest production.

Authors such as Traoré (1996) and Freudenberger (1993a) argue that Senegal has not had an integral pastoral policy since independence. As illustrated in the series of land laws referred to below, policy dealing with pastoral land use tends to be subordinate to agricultural policy and fails to take into account or support traditional pastoral institutions and practices revolving around the mobility of localized or transhumant herding. The notion of 'productive' use of land remains undefined in these statutes, even though it is a fundamental criterion of land allocation or withdrawal.

For instance, the law of 17 June 1964 (*Loi relative au domaine national*) replaced traditional forms of land tenure with state holding and control of the land and gave rural councils the power to make land management decisions. Arrangements generally favoured agricultural development to the exclusion of pastoral use, disrupted the traditional rangeland zonations and increased competition between local and transhumant herders for local resources. Later, the law of 19 April 1972 (*Loi relative aux communautés rurales*) gave rural councils the authority to allocate land for 'productive' use or to reallocate it. It referred to pastoral activities but mostly with the aim of limiting livestock encroachment on agricultural fields and increasing farmers' claims to their cultivation areas. The decree of 10 March 1980 was a step forward in that it allowed the official designation of rangelands and protected them and livestock tracks from clearance and cultivation. Nevertheless, even in lands zoned for animal husbandry, pastoral management patterns are not recognized. Furthermore, the 'pasture conservation commissions', which are required to file requests for grazing reserves, are heavily dominated by state personnel and the filing process is complicated and lengthy. Recent rangeland management experiences in the northern Ferlo region have consisted of controlled grazing contracts which have allocated large land tracts to influential herder families. However, these fenced-in and fiercely guarded areas exclude access by other local and transhumant herders and create greater tenure insecurity and land-use imbalances between users.

Fig 5.8 Cattle herded through *Faidherbia albida* parklands.
R. Faidutti

In Senegal and other Sahelian countries, bitter conflicts resulting from livestock straying into fields result from the fact that policies have not recognized the land management needs and practices of pastoralists and that legal texts are used to their detriment. Conflicts are particularly intense in the southern Ferlo region of Senegal, because this region borders

the area of active groundnut production which is politically and economically controlled by the powerful Mouride brotherhood. Needs for additional cropping land are readily and officially satisfied by rural councils who interpret legal provisions in favour of agricultural use. Farmers also establish fields unofficially and later seek to legalize their access. As a result, fields are 'straying' and causing damage to herds. Land where pastoralists naturally enjoyed secure tenure, including areas recognized by the same rural communities as rangeland under the 1980 Law, is being taken away. A further threat is the increasingly widespread settlement of farmers around boreholes in order to set up horticultural operations. This inevitably leads to damage by herds which are pushed into areas they do not traditionally use as they are characterized by poor grazing resources, no water points and few silvipastoral reserves.

In addition, there is increasing pressure in the area from the Mouride marabouts to declassify gazetted forests, which pastoralists traditionally rely on to cope with dry-season shortages of grazing resources, for use as land reserves for groundnut cultivation. Land allocation and degazetting of forests for the benefit of the agricultural sector contribute to intensified conflicts, support the marginalization of herders and detract from traditions of concerted conflict management.

In spite of their importance in Sahelian economies, the needs of pastoralists are, for the most part, neglected in forest codes.

The allocation of resources away from pastoralism causes the natural landholding balance between crops and livestock to break down and this generates conflicts. A solution to this situation would require a full recognition of pastoralism as a valid form of land use and the incorporation of the diverse local pastoral knowledge, practices and authorities into the policy-making process. When appropriate, conflicts might be settled in favour of pastoralists, for instance by fining farmers for unauthorized spontaneous settlement, or use of reserved areas, or absolving herders for damage caused. Traditional conflict management institutions, such as the *Ay Njambur* (Wise Men) Commissions with equal representation of freely chosen parties, can be spontaneously convened to settle conflicts before the official administration becomes involved.

Implications for improved parkland management

Whether or not legislative changes result in more decentralized parkland management depends on how effectively they are communicated to, and applied by, the various levels of the forest administration. Based on a reading of the legal texts, it would seem that Sahelian forest codes have moved significantly towards allocating local individuals and communities a share of the national land and forest domains. However, important constraints remain to the empowerment of rural populations in managing local forest resources with less direct state regulation. Effective and decentralized forest management are unlikely to be achieved simply through the promulgation of new laws, but will be the result of a slow and iterative process. Most of the following recommendations for alleviating obstacles to the improved management of agroforestry parklands have been specifically identified in McLain (1992).

A basic requirement for effectiveness and local acceptance of forest legislation is that populations who rely on forest resources for their livelihoods need to be engaged in its formulation. Methods to facilitate local involvement in the further development and revision of natural resource regulations will therefore need to be tested. Taking into account the existence of local variations in ecological and socio-economic conditions, the design of legal provisions may need to include basic guidelines for application at the national level as well as specific regulations for implementation at province or district levels.

The state cannot effectively manage all forest resources it has claimed control over and may need to recognize that individuals and communities are in a better position to manage some types of forest resources. Land categories should be clearly defined according to existing land and forest rights. The forest domain protected in the name of local collectives, as it is currently specified in Burkina Faso, Mali and Niger, could distinguish between at least three forest land types over which individuals, communities, or groups of communities, have recognized rights. The non-forest domain needs to be treated separately, giving landholders the ability to exercise more control. Resource regulation, except in the case of large-scale exploitation or sensitive areas, could be mostly devolved to individuals and communities through management or use contracts with central or local government authorities. The role of the state needs to be adjusted according to the capacity of other institutions to manage forest resources effectively. It would focus on the provision of technical assistance and help to mediate resource allocation in community and supra-community forest domains.

Additional legislative modifications specific to parkland zones appear necessary. First, the distinction between the forest and the non-forest domains ought to be clearly stated to avoid arbitrary application of the law by forest agents and farmer uncertainty. Because tree resources in fields are generally crucial to farmers' livelihoods, landholders would benefit from having a greater amount of control over trees on their lands, including the right to fell or prune, and to collect tree products for household or commercial purposes, without the need to obtain a permit. Where their rights to land and tree resources are clear, landholders have a natural interest in ensuring their sustainable use. Tree management in the non-forest domain should therefore mostly be the responsibility of landholders.

Secondly, the reliance on permits, albeit free, for felling trees in the protected forest domain, takes away the rights to trees which populations have planted or protected and is thus a disincentive to local participation in agroforestry. Free authorizations should be eliminated, at least in agricultural lands. If established for classified forests, they should be accompanied by clear criteria stating when they can be granted or refused, together with an appeals process for refusals.

Thirdly, the clause in most codes prohibiting use of protected species is often a disincentive to farmers wanting to conserve and actively manage naturally regenerated trees in their fields. Indigenous management regulations already exist for economically important parkland species. It would be better, therefore, if restrictions on the use of trees outside classified forests, at least in parkland zones, were limited to endangered species. Any such restrictions should only concern the felling of live individuals, while allowing pruning without prior authorization to ensure optimal management.

A greater emphasis is needed on the importance of grazing resources. This includes the recognition of the rights of pastoralists to use lands for forage production and to exercise exclusionary rights to these lands. Because spatial and temporal patterns of use include a variety of grazing lands and watering points, legislation needs to permit the establishment of resource management areas encompassing a series of administrative and ecological zones. A possible solution would be to have the access to resources within theses areas regulated by pluralistic management committees representing all user groups.

The lowering of fine rates in harmony with income levels and the price of tree products could help to reconcile farmers to the forest management approach of the forestry administration. Fines could also be set according to the quantities harvested. Forest services might also consider how they could devolve the

authority for administering specific categories of common fines to representative local bodies.

Rural residents' negative experience of the application of forest regulations is in part the result of foresters' incomplete knowledge of these rules. This could be counteracted by more effective communication of legal provisions and associated ministry guidelines throughout the forest administration. More efforts need to be dedicated to the training of forest agents and to public education on the rights and responsibilities of individuals, communities and the state regarding natural resources. Regular refresher courses could inform agents at all levels about the basic legislative texts as well as any revisions. Forestry schools would benefit from staff properly trained in forest legislation, the provision of updated textbooks, and the inclusion of topics such as resource use conflict and management in the curriculum.

Information on forest laws also needs to be made available to farming populations. Extension materials could include translations of the forest code into all major spoken languages, manuals summarizing tree-use rights, permit requirements and criteria for refusing them, information on recourse channels, as well as cassette versions of legal texts. Regulations could also be broadcast on the radio in local languages. Forest services may want to explore possibilities for designing a legal extension programme specifically geared to nomadic pastoralists who are often held responsible for forest law offences. Women are another important target group who are often left out of extension programmes and could be reached through women's groups or literacy programmes.

At the same time as legislative change, McLain (1992) emphasized the need for changes in forestry institutions in order to improve the effectiveness of forest enforcement and extension programmes. Timely and regular salary payments could alleviate the financial problems of forest agents and reduce incentives for corruption. A fiscal decision to set aside a higher percentage of fine receipts for local forest administration units would help to cover operational expenses, for which agents are currently often responsible. To avoid the arbitrary application of forest laws, the development of an accessible and inexpensive legal recourse system to appeal forest citations would be beneficial.

Interview data in Mali suggest that forest agents believe that rural populations are not interested or not capable of managing local natural resources effectively. Foresters are reluctant to cede decision-making and revenue-raising powers to local user groups and individuals. The transfer of authority and appropriate implementation of local management plans will require a positive change in the attitude of field agents towards the capacity of individual farmers and communities for successful forest management. Consistent with a shift in the mission of forest services from rule enforcement towards forest extension, forest agents should be provided with formal and informal training in participatory research, improved tree management techniques, and social sciences. Forest services could also consider establishing internal divisions in charge of natural resource policy.

Control of forest commons

Common property forest resources found between villages are often characterized by poorly articulated tenure regimes, where open access can lead to resource mining (Freudenberger, 1993a). Geographical boundaries between village territories may be unclear. These commons may be claimed by several local communities based on rights of first settlement or later allocation, and can represent a source of latent

disputes. There is a lack of effective institutional mechanisms at the scale of groups of concerned villages to coordinate the use of resources and arbitrate conflicts. Governance problems in these commons are further exacerbated by external interventions which are supported by the state. Much to the dismay of villagers in eastern Senegal and elsewhere, forest lands are intensely encroached by outside organized groups of wood collectors for the charcoal and fuelwood supply of cities.

Ribot (1995a) argues that centralized forestry policies in Senegal have placed control over these forest commons into the hands of non-local groups, depriving rural communities of the decision-making power and benefits of managing their local resources. Legislation first assigned control of the entire forest domain and all commercial forest exploitation to the forest service. It recognized villagers' usufruct rights and provided rural councils with the responsibility for managing them, but not the ability to protect the forest they used from commercial exploitation. Separating use and commerce of forest products, the forest code limited villagers' access to commercial forestry activities through permits and licences which were ultimately allocated to powerful urban merchants. Policies controlling production, transport, and prices, as well as who and how many people could enter the market, progressively restricted and excluded rural populations from participation in the marketing of wood and charcoal. In addition, merchants generally use migrant labourers for cutting and charcoal-making, so that rural villagers rarely participate in either production or marketing.

Furthermore, restrictions on cutting and charcoal-burning are not uniformly implemented; this reinforces control of traders to the detriment of local residents. The non-enforcement or selective allocation of licences, permits, excess quotas and exemption from prosecution allow state officials and forest agents to cultivate alliances with powerful merchants. Cases when rural councils keep charcoal producers from entering local forests but are overruled by state representatives are not uncommon (Freudenberger, 1993a). In these alliances officials gain in economic, political and social terms through the control of allocation while merchants gain more exclusive control over the forest sector. In fact, half the Senegalese charcoal trade is controlled by some 20 out of 4000 registered merchants, some of whom make annual profits of hundreds of thousands of US dollars. As a result, farmers lose subsistence and income opportunities derived from local forests. A more detailed examination of local involvement in the fuelwood sector is provided in the next section.

Fig. 5.9 Canoe hollowed out from a *Prosopis africana* trunk, Bec de Canard, Cameroon. ***C. Bernard***

The depletion of natural resources including fuelwood, game, forest foods, fodder, and water resulting from charcoal production often results in social conflicts, especially with women. While some villagers wish to expel charcoal producers, men benefit from charcoal production through the hiring out of huts, carts, as well as provision of meals. Furthermore, merchants, to whom the legal system gives control over forest production and commercialization, often manage to gain the consent of village chiefs by drawing on their

relations with significant religious and political figures. Village dynamics and their broader political and economic context tend to dilute potential conflicts and support the existing chain of access to charcoal production.

Some villages, however, have tried to protect their natural resources by strengthening or creating inter-village organizations and attempting to gain influence in rural councils. Communities in the Middle Senegal River Valley have jointly attempted to close access to outsiders while others, fearing that the state would not support them, have instead opted to sell their wood resources to charcoal makers (Fischer, 1994). In western Senegal, communities collectively attempt to protect their natural forests from uncontrolled tree cutting and grazing, sometimes requesting the authority to punish illicit activities from the forest service (Seyler, 1993). However, the efficiency of these organizations often remains dependent on rule-making powers which are centralized at higher political levels.

Devolution of access and use rights to local communities is recommended to promote a higher efficiency of local resource management due to greater local knowledge, lower transaction costs due to the proximity of forests, as well as better decision-making due to the internalization of social and ecological costs into commercial decisions (Ribot, 1995a). Allowing local participation also favours equity and rural development. Such devolution and further institutional support by the state is a prerequisite to enhance the villages' capacities to manage these common lands sustainably. The development and effectiveness of these village organizations is a positive basis for the devolution of rights, responsibilities and benefits at the local level.

Local participation in the fuelwood sector

Fig. 5.10 Blacksmiths using charcoal from *Prosopis africana*, Maroua, Cameroon *C. Bernard*

A series of national in-depth reviews of forest policies affecting local control and management of fuelwood resources have been undertaken in Burkina Faso, Mali, Niger and Senegal (Ribot, 1994a, 1994b, 1994c, 1994d) and synthesized (Ribot, 1995b). Analysing how the new forest policies integrate rural populations into forest resource management, Ribot noted that their control over the decision to dispose of their forest resource and the benefits deriving from their participation in fuelwood management is still uncertain and likely to be limited. Several suggestions are offered for improvement.

Participatory forest management relies on two central issues, the devolution of control over commercial decisions to local populations, and participation through locally accountable representation (Ribot, 1996). In a

major innovation, Mali's new code gives communities the possibility to remove from commercial access (or classify) any forest or forest species for protection measures deemed appropriate (République du Mali, 1995). However, the smallest decentralized territorial collectives to which this right is devolved consist of a minimum of 15 to 20 villages. Because representation is through lists of candidates proposed by registered political parties, it may fail to mirror the diversity of interests in local populations. Burkina Faso's 1997 forest law gives local collectives the possibility of classifying their forests, thus giving them some control over commercial forest exploitation (Burkina Faso, 1997). Putting forest management into the hands of local collectives should ensure local participation in both the costs and benefits of forest production and management. However, production *groupements* (associations), as currently exist in the Nazinon forest project, for example, include people with an economic interest in commercial forest exploitation but do not represent the diversity of users present in the whole community. In Senegal, allocation of commercial management rights to local collectives is at the discretion of the state. There is no legal mechanism to allow rural communities to protect forest lands if they so wish. They even risk losing their forest concession to external parties if they decide not to harvest it. Nevertheless, in contrast to the old code, new Senegalese regulations allow communities to participate in wood production activities and the resulting revenues, and even to obtain a share of the National Forestry Fund.

The law in Burkina Faso, Mali and Senegal states that local forest management should be carried out in accordance with management plans (Burkina Faso, 1997; République du Mali, 1995; République du Sénégal, 1993). These are elaborated by forest services and approved by local collectives. Rural communities can sell wood-harvesting rights in forest plots in their locality provided that they reforest and protect regeneration through these forest management contracts. But questions remain concerning the contents, the degree of local say and influence on the plans, the responsiveness of the forest service, and the existence of checks and balances to avoid plans being imposed on villages. The Senegalese law goes further in defining forest maintenance and replanting obligations (but no recourse) for local collectives, as well as giving the forest administration the authority to monitor management and revoke rights. It therefore gives the forest service a high level of control over fuelwood-related rural labour.

Being responsible for forest regeneration and protection, communities, particularly in Senegal, run the risk of selling forest plots for harvesting for less than it will cost in labour and funds to manage them (Ribot, 1995a). Several factors may make them more likely to enter into inappropriate production agreements, such as their inexperience in estimating costs and impacts of production, the threat of losing their forests to outside woodcutters and merchants, short-term economic needs, competition from other villages, persuasion by powerful figures, pressure by forest agents, etc. Rural councils, which are chosen to represent communities, are elected from lists drawn up by urban-based political parties, and take part, like village chiefs, in wider relations with merchants, foresters and religious and political leaders. Therefore, they are not accountable to local populations and are not bound to internalize the social and ecological costs and benefits of forest production. Moreover, the unequal distribution of tasks and decision-making powers within villages is likely to affect who shares in the risks and benefits of forest production. Women are particularly likely to bear the costs of forest destruction. It is thus crucial that they are represented in decision-making bodies. Finally, given their inexperience, there is also a risk that communities may overexploit local forests when given the choice to participate in their large-scale commercial use.

In maintaining control over forest management plans and quotas, forest services have amalgamated technical and economic decisions in the name of the protection of national forest resources. Ribot (1995b) cites evidence that Sahelian forest vegetation regenerates vigorously after woodcutting and can sustain rotations of 4 to 12 years. Agricultural expansion and possibly wild fires are more serious threats. He therefore questions the need for detailed management plans or production quotas and instead proposes minimum forest management standards which rural populations would meet with the technical assistance of the forest service. He also argues that the need to increase the rural price of fuelwood in order to promote forest conservation over agricultural expansion is more pressing than management planning. Laws should further separate the various roles of the forest service, assigning tax collection to elected local representatives, control of tax receipts and policing to the police services, and forest extension to foresters.

Communities have faced unfair competition from alternative legally-supported production by parastatals, the army or through concessions and permits to access wood outside of locally managed forests. Local groups will not be able to obtain higher income from their products if these parallel forms of production continue. A solution is to extend local control over all forest lands except classified forests, thus eliminating non-locally controlled access to forests. Provided that rights are devolved to the smallest level of local collectives, this would place all production under the same management requirements and would ensure that costs of production are internalized. The control of local populations over the commercial use of forests and the obligation to have usufruct rights in the forests in order to participate in harvesting would also contribute to greater scarcity and higher revenue from the resource.

In order to increase farmer participation in benefits of forest production, Ribot (1995b) proposes a series of measures including fixing producer prices, as done in Burkina Faso, and channeling taxes back to communities. Market access for forest communities needs to be facilitated. He recommends the removal of state support of market regulations (permits, licences, quotas and the support for or requirement of merchant cooperatives) which help concentrate market benefits with an oligopoly of transporters/merchants. Participation in fuelwood management should be limited to active woodcutters. The flow of information on market participants and fuelwood prices, which is currently centralized by merchants and transporters, should also be extended to rural producers, possibly through the forest service.

Summary

In general, the extended family is the socio-economic unit in rural West Africa and farms include collective family fields and individual fields allocated by the household head. One acquires land through membership in a lineage by first occupancy, inheritance, gift, customary authority and borrowing. Borrowed land is a major land category, making up 25-50 percent of the cultivated area in Burkina Faso. It permits equitability of land use, flexibility to adjust to demographic changes, and efficiency, as the initiation and termination of loans reduce overcultivation. It also reinforces social stability and cohesion, and evidence shows that it does not preclude adoption of common land intensification practices. When outside legal interventions are superimposed on traditional land tenure arrangements, farmers actively seek to limit their influence on local natural resource management systems.

Sahelian rural communities have created an intricate set of rules and conventions, including rights, obligations and sanctions regulating access and sustainable use of parkland and forest resources, particularly for those of great use and exchange value. Arrangements for the harvest of fruit and other tree products as well as tree felling ensure equal access for all community members, reduce protection costs and minimize intra-community conflicts. They also ensure that resources are collected in quantities which allow sustainable use, at times which are biologically appropriate, and sometimes even conducive to best commercial opportunities. Forest management regulations can be applied on a wide geographical scale through intervillage coordination or the broad political authority of rulers. They are effectively enforced through sanctions of a social, economic and religious nature. Prohibitions or taboos can sometimes reveal traditional management institutions which are threatened by new socio-economic influences. These institutions may have receded, yet some also display resilience and flexibility and are perpetuated from generation to generation, or are created anew to adjust to current conditions.

More individual tree tenure practices also exist within these common property management regimes. All rights pertaining to trees in fields are generally held by holders of inherited or lineage land. Private rights apply on intensively managed lands, yet farmers may allow communal access to some tree products. In turn, collective regimes prevail in fallows and uncultivated lands. Permanent landholders usually reserve for themselves exclusive tree planting and felling rights, but may encourage tree pruning and gathering of tree products by other community members. Restrictions occur depending on the value of the species and quantities harvested. In some places, village leaders preempt lineage heads in the appropriation of tree crops. The increasing value of resources, often linked to a high population pressure, contributes to stronger individual claims. In the Sudano-Guinea zone rights to high-value perennial crops are generally clearly articulated and regulated. Authorized to prune and gather tree products, land borrowers have no disincentive to regenerate parkland trees. However, projects should be aware of how promoting tree regeneration may influence tree tenure and assist all rightholders in defining mutually satisfactory and secure rights to improve participation.

Because planting confers ownership, permanent landholders generally do not authorize tree planting on loaned land. This is reflected in the lower densities of planted trees on borrowed than inherited land, and the lower probability that certain social groups, who primarily rely on land loans, participate in planting. Failure of tree planters to obtain permission from landowners can result in serious conflicts. Planting of exotic and commercially valuable species is often prohibited

while indigenous species encounter less resistance. The economic value of plantations is a powerful driving force in the commoditization of land. Traditional tenure regimes nevertheless give landowners and borrowers the opportunity to design informal agreements in which tree planting is of clear benefit to both parties.

Women have usufruct rights to land loaned by their husbands or kin group heads. However, the year-to-year mobility of these plots, which was found to vary widely geographically, can be a serious constraint to long-term investments. The right to plant trees is usually denied. Consequently, they are less likely to participate in tree-planting activities. However, because they are entitled to prune trees on their land and also have relatively secure gathering rights, they participate actively in the protection of natural tree regeneration. Because of their distinct roles in the household economy, men and women often differ in their management strategies regarding trees, and conflicts arise. A number of cases suggest that women's land and tree rights and living conditions are more vulnerable to land use changes, including breakdown of fallow cycles and the development of horticultural operations, than those of male landholders.

Superimposed on traditional land and tree tenure regimes are forest codes, originally written for the whole of French West Africa. The general trend for colonial and postcolonial administrations was to reduce the influence of customary village authorities over land rights in order to achieve resource management based on centralized state control. More recently, most Sahelian countries have revised their forestry legislation but many basic similarities remain. In principle, the new forest codes go some way towards recognizing customary rights and, in some cases, devolving management of certain forest resources to local populations. In practice, implementation is complicated by ambiguous definitions of different types of forest resources. Farmland technically falls outside the forest domain, but because rural landholdings are often unregistered, they continue to fall under the state's control. Thus many restrictions originally intended to protect forest trees are also applied to trees on farms and in fallows, with the result that farmers are prevented from carrying out basic management activities such as pruning, thinning or coppicing, which are crucial in optimizing their land use systems.

Forest codes are often poorly understood by rural people and forest agents alike. Faced with a lack of human and financial resources, most forest services are unable to enforce regulations properly, and individual agents often take the option of interpreting obscure permit requirements to their own benefit in order to supplement their meagre salaries. This serves to further disenchant farmers, for whom forest agents are among the most disliked of government officials. Moves to encourage and officially recognize local management of resources will need to be accompanied by institutional change within forest administrations with far greater emphasis given to training of staff in participatory approaches and acknowledgement of the often sustainable nature of traditional management practices.

In spite of their importance in Sahelian economies, pastoralists are a group whose special needs are, for the most part, neglected in both the old and revised forest codes. In some cases, attempts are now being made to designate rangelands and protect them from clearing and cultivation. As with community-based forest management, however, systems to ensure local control of grazing resources are often difficult to establish and easily taken over by elites. Another area of potential conflict are the forest commons between villages, the rights to which may be disputed under both traditional and modern law. These are increasingly encroached (sometimes with government approval) by woodcutters and charcoal burners from outside the area, leaving communities frustrated in their attempts to

manage and benefit from their local resources. Devolution of access and use rights will not happen overnight, but will require a lengthy process of learning – both by forest administrations and local communities – to achieve the long-term aim of more sustainable management of forest resources.

PARKLAND PRODUCTION LEVELS

CHAPTER VI

Production of parkland trees

As forest resources decline and demand for some forest products increases, people tend to rely more on obtaining desired products from trees growing on farmland. This trend has led to both the active regeneration of agroforestry parklands (Bergeret and Ribot, 1990; Joet *et al.*, 1998; Cline-Cole *et al.*, 1990) and their degradation (Gijsbers *et al.*, 1994; Lericollais, 1989) in different semi-arid West African locations. Similar patterns of reliance on farmland trees appear elsewhere in Africa and Asia (Holmgren *et al.*, 1994; Falconer, 1990; FAO, 1995). In all cases, parklands, and resources outside forests more generally, have the potential to meet the demand for a variety of forest products, and can sometimes offer higher production of specific commodities than natural forests.

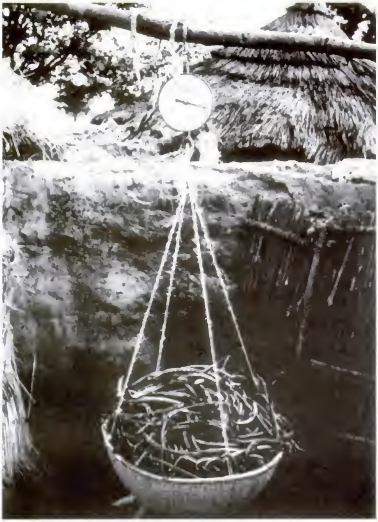


Fig. 6.1 Weighing pod production of a single *Parkia biglobosa* tree, Thiougou, Burkina Faso.
J.-M. Boffa

The sustainable management of parklands is therefore of increasing importance, and should begin with a thorough knowledge of parkland growth rates and production levels, including wood, fruit and foliage, as well as factors affecting them. This knowledge is also necessary, especially for forestry planners, in order to define the percentage of supply to be expected from these systems as compared with other forest systems and the degree to which they can meet community needs for these products.

In addition, as harvest levels exceed the ability of a species to regenerate, a process of domestication can act to supplement wild resources (Chapter 4). As a result, several aspects related to production need to be elucidated. These include measuring the variation in desirable traits in parkland species, establishing whether this variation is of genetic or environmental nature, and deciding on the most appropriate interventions needed to improve production (phenotypic selection, silvicultural interventions or a combination of both). Knowledge of production patterns will be instrumental in efforts to estimate and match actual and potential supply and demand of parkland products, and in supporting decisions about appropriate improvement levels. Production data are also necessary for cost-benefit evaluations of trees in agroforestry parkland systems (Chapter 7).

A large body of data shows that agroforestry parklands represent a major production site, not only in number but also in quantity of non-timber forest products (NTFPs). In villages bordering the Monts Mandingues Classified Forest in Mali, 63 and 51 percent of NTFPs recorded in the study originated from fallow lands and crop fields respectively (Gakou *et al.*, 1994). As expected from its proximity, the largest proportion (90 percent) of NTFPs also originated from the natural forest. In the Bassila region of Benin, 12 of the 16 main marketed NTFP species were found in fields and fallows as well as, in some cases, their original savanna and forest vegetation types. Fields and fallows greatly outweighed forests and savanna zones in terms of the volume of NTFPs used (Schreckenberg, 1999). In the North Central Peanut Basin of Senegal, fields and fallows provided two-thirds of collected grasses, medicinal plants, and service wood and about 75 percent of fuelwood, fruit, and fodder, while the remainder was collected in unexploited zones of the rural landscape, mostly in bottomlands (Seyler, 1993). Whenever possible, this chapter provides references focused on parkland locations including fields and fallows, but references to forest products which do not differentiate between parkland and other types of forest lands are also included.

Parkland products can be classified into a number of major use categories such as: food, fodder, fuelwood, construction materials, wood for tools and utensils, medicinal items and other products. Many plant parts serve multiple purposes. Rather than attempting to quantify the contribution of agroforestry parklands in each use category, the following sections review information on production of the various parts of parkland trees, including fruit, foliage, gum and wood.

Fruit production

Flower and fruit production in parkland trees vary more than foliage production between species, between individuals of the same species, and from year to year (Breman and Kessler, 1995). Only for a few parkland species is detailed information available on fruit production. Data for *V. paradoxa* and *F. albida* are presented in Tables 6.1 and 6.2 respectively. Pod production in *P. biglobosa*, reviewed in Hall *et al.* (1997), ranges from 15 to 130 kg/tree. A few general production figures are provided for species producing commonly eaten fruit in Booth and Wickens (1988) and von Maydell (1983). These include:

- *Balanites aegyptiaca*: 100-150 kg/mature tree
- *Boscia senegalensis*: 3.9 kg/ha
- *Moringa oleifera*: 1 000 pods/tree
- *Ziziphus mauritiana*: 80-130 kg/tree in Africa
- *Tamarindus indica*: 150-200 kg/tree
- *Bombax costatum*: up to 1 500 capsules (fibre)/tree.

Surprisingly, few production data exist for several important parkland fruit species, such as *Adansonia digitata*, *Borassus aethiopum*, *Hyphaene thebaica*, *Lannea microcarpa*, *Sclerocarya birrea*, *Strychnos spinosa* and *Ximenia americana*.

Fruit production in parklands varies between individuals of the same species and fluctuates greatly on an annual basis. For instance, Dunham (1990) reported an inter-annual variation from 5.4 to 290 kg in a given *F. albida* individual. The average nut production of 50 *V. paradoxa* trees varied by a factor of five in two consecutive

Table 6.1 Fruit production in *Vitellaria paradoxa*

Authors	Location	Trees	Years	Tree diameter (cm)	Nuts/ tree	Fresh fruits/tree[a] (kg)	Fresh nuts/tree[a] (kg)	Dry nuts/tree[a] (kg)	Kernels/ tree[a] (kg)
Delolme (1947)	Ferkessedougou	49	1944-45	40 to 80	3268	(56.8)	28.4	19.8	13.8
Ruyssen (1957)	Ferkessedougou	10	1944-48	-	2874	-	-	-	-
	Ferkessedougou	100	1944-48	-	-	(56.4)	28.2	(16.9)	(11.8)
	Saria	10	1935-44	-	2778	(30.4)	(15.2)	9.1	(6.4)
	Katibougou	20	1911-15	21 to 95					
Mean = 41	-	(17.6)	(8.8)	5.3	(3.7)				
	Ina	25	1949-50	-	2498	57.3	26.8	(17.4)	12.2
	Ina	16	1949-50	-	-	29.4	(14.7)	(8.8)	(6.1)
Desmarest (1958)	Niangoloko	217	1954-57	51≤57%≤82	-	(20.6)	10.3	(6.2)	(4.3)
Dao (1989) in Bagnoud *et al.* (1995b)	Sikasso	26	1989	Mean = 26	-	20	(10)	(6)	(4.2)
Boffa (1995)	Thiougou	54	1993-95	10 to 44 Mean = 25	757	18.8 [b]	7.0 [b]	(4.2)	2.4
Serpantié (1997a)	Bondoukui	70	1995	24 to 48	-	-	-	-	9.4
	Bondoukui	100	1996	24 to 48	-	-	-	-	2.8

Notes:
[a] Numbers in parentheses were derived from weight ratios (fresh nut = 0.5 fresh fruit; dry nut = 0.6 fresh nut; dry kernel = 0.7 dry nut) provided by Ruyssen (1957).
[b] Measured in 1994 and 1995, two years of relatively high production.

Table 6.2 Pod production in pruned and unpruned *Faidherbia albida* trees

Source	Unpruned trees kg/tree	Pruned trees kg/tree	Trees	Tree size	Comments	Location
Lemaître (1954, in Felker, 1978)	6-8		-	20-year-old trees		Zinder, Niger
Jung (1969)	125		5	40-110 cm diameter, 30-80 years old	Two 2 m^2 litter baskets/tree	Bambey, Senegal
Gouzales (unpubl.) in Lepape (1980)	75 in 1967 55 in 1968		6	Mature and well developed		Ribeira de Trinidade, Cape Verde Islands
Wickens (1969)	135		4			Sudan
Cissé (unpubl.) in Le Houérou (1980)	10	6	2			Niono, Mali
Le Houérou (1980)	50-150	10-20	n/a			n/a
Dunham (1990)	106 (sample cages) 145 (total) collection		4	256-360 m^2 in crown area 8 years	Dry weight of fallen ripe fruits; Park,	Mana Pools National Zimbabwe
Depommier and Guérin (1996)	2.2	-	20	Dbh 16-80 cm	3-4 years	Watinoma, Burkina Faso
Depommier and Guérin (1996)	13.2	-	34	Dbh 32-80 cm	2 years	Dossi, Burkina Faso
Depommier and Guérin (1996)	~8	~0.8	5	-	1 year in each of unpruned and pruned conditions	Dossi, Burkina Faso
Depommier and Guérin (1996)	7.6	0.9	5	Dbh 67 cm	Bottomland, 2 years in each of unpruned and pruned conditions	Watinoma, Burkina Faso
Depommier and Guérin (1996)	0.4	1.1	5	Dbh 62 cm	Upland, 2 years in each of unpruned and pruned conditions	Watinoma, Burkina Faso

years in southern Burkina Faso (Desmarest, 1958). Also in Burkina Faso, Boffa *et al.* (1996a) found that 40-50 percent of trees in a natural *Vitellaria* population contributed only 15 percent of the total stand production, while the top 20-25 percent of the population produced over half of total yields and about 15 percent of trees were consistently high producers.

Annual variations in *Vitellaria* fruit production are believed to follow cycles of two or more years, yet a relationship with climatic parameters has not been clearly identified. Early initiation of flowering due to higher minimum temperatures during the flowering period may contribute to higher fruit production (Desmarest, 1958). Fluctuations may also result from differential success in pollination. Thus only 25 percent of hermaphrodite flowers produced fruit due to a combination of physiological factors, lethal genes and lack of fertilization which were particularly pronounced in late or inaccessible central flowers of *Vitellaria* (Guinko *et al.*, 1988, cited in Serpantié, 1997a). A combination of a large number of flowers,

synchronized flowering (favouring pollination), high humidity and good site quality resulted in exceptionally high yields in Burkina Faso (Serpantié, 1997a).

Potential fruit production tends to increase with tree size. *Vitellaria* starts producing at age 15-20; yields rise rapidly and become significant around age 40-50, and start declining only after 200 or 300 years of age (Ruyssen, 1957). A significantly positive relationship between tree diameter and number of nuts produced was found in Thiougou (Boffa *et al.*, 1996a) as well as in the five-year Katibougou data presented by Ruyssen (1957). High production in *Vitellaria* appears to be associated with specific tree form and high foliage density, which may be genetically controlled. No relationship between tree size and pod yield in *F. albida* could be established in Watinoma, Burkina Faso, where most trees are pruned and yield variability was very high. In contrast, pod production could be accurately predicted by a regression equation based on crown surface area and tree height in nearby Dossi (Depommier and Guérin, 1996). In Mali, fruit production of *Acacia raddiana* was correlated to tree diameter on two types of site quality (Cissé, 1983).

Pruning affects production considerably. In *F. albida*, high-intensity pruning reduces fruit yields in the following year by a factor of two to ten (Table 6.2). The effect of plant parasites (*Tapinanthus* spp.) on fruit production has also been documented but not quantified (Boussim *et al.*, 1993a, 1993b).

Site conditions also influence yields of fruit. The lack of nutrients available for fruit development may explain spontaneous flower abortion and inter- and intraspecific variation in fruit production (Breman and Kessler, 1995). As soil conditions improve, standing biomass and average plant height increase, as may fruit production. For instance, *Acacia raddiana* pod yield in trees of a given size was twice as high on deep as on shallow soils (Cissé, 1983). While pruning drastically reduced *F. albida* fruit production in bottomland locations in Watinoma, on upland sites the initially low yields were not greatly affected by pruning. This finding was attributed to differences in site conditions, along with the possible late effect of pruning in previous years (Depommier and Guérin, 1996). Results of fertilization and weeding experiments for *Vitellaria* have not been conclusive (Picasso, 1984).

Fig. 6.2 Juicy fruit of *Lannea microcarpa* are an energy-rich snack for children in the dry season, Thiougou, Burkina Faso.
J.-M. Boffa

Farmers and researchers often claim that yields of *Vitellaria* and *Parkia* trees found in the bush are lower than those of trees in cultivated fields, yet this appears to depend on fallow age, management, and soil type. In Burkina Faso, yields of *Vitellaria* trees in fields and fallows less than ten years old located on deep fertile soils did not differ significantly (Serpantié, 1997a). However, plant competition in older fallows is expected to reduce fruit production. In the Bassila area of Benin, estimated yields of small and large *V. paradoxa* were respectively low and high, and not significantly different in bush or field conditions. In contrast, medium-sized trees (28-37 cm in dbh) produced significantly more in fields than in the bush (Schreckenberg, 1996). Regular weeding and a light, early fire (or grazing) lead to higher fruit production, but cannot explain all annual variability.

In conclusion, fruit production in parkland trees is highly variable within species and between years as a result of genetic and several environmental factors. This variation is reflected in the various production assessments available. Compounding this variability are the logistical constraints of measuring resources

which are highly valued by people and livestock and used on a daily, sometimes open-access basis. Research to establish reliable, standardized participatory assessment techniques for parkland tree production would be beneficial. Consistent with the low intensity of parkland tree management, there is generally limited knowledge of the factors governing fruit production. As domestication of parkland species proceeds, additional research is needed on intraspecific variation, the reproductive biology of parkland species and the influence of climatic and edaphic factors on reproductive success and productivity. Irrigation may be instrumental in assessing the role of soil water status at the beginning of the dry season. Fertilization and weeding experiments could also be pursued.

Foliage production

The measurement of leaf production in agroforestry parklands is important because of the role of leaves as food for people, browse and fodder as well as a litter component for soil nutrient cycles.

Foliage produced decreases as a proportion of standing biomass with increasing tree age and size (Breman and Kessler, 1995). Small young plants have the highest ratio of foliage production to standing biomass. This ratio can reach up to 10 percent in the Sahel zones as compared with about 5 percent in the Sudan zones. In contrast, large mature trees have the highest absolute foliage yield. Foliage production is lower in years of low rainfall, and higher in bottomland sites due to a higher availability of nutrients and water.

Foliage production in trees has mostly been studied in natural ecosystems in the Sahel which may not always qualify as parklands. Studies reviewed in Breman and Kessler (1995) give an order of magnitude for the leaf production per tree for the following species: *Acacia senegal* - 1 kg; *Acacia laeta* - 0.8 kg; *Acacia seyal* - 2.9 kg; *Balanites aegyptiaca* - 0.8 kg; *Combretum ghasalense* - 4.5 kg; *Commiphora africana* - 0.9 kg; *Grewia bicolor* - 2.1 kg; *Guiera senegalensis* - 0.2 kg; *Pterocarpus lucens* - 3.9 to 6.3 kg; *Sclerocarya birrea* - 14.3 kg.

Fig 6.3 *Borassus aethiopum* leaves are collected for use in basket-making.
R. Faidutti

More information is available for *F. albida* than other parkland species. Average foliage production in five *F. albida* trees with diameters of 40-110 cm was 58 kg/tree or 3 percent of standing biomass in Senegal (Jung, 1969). Miehe's (1986) estimate was 20-50 kg/year for pruned trees in Koronga, Ethiopia.

Insights on foliage production in *F. albida* were also provided by artificial pruning experiments consisting of 100 percent crown reduction in Watinoma and Dossi, Burkina Faso (Depommier and Guérin, 1996). Foliage production during a one-year interval between two such prunings ranged from 3 to 22 kg/tree for trees with a dbh of 16-48 cm and 15 to 40 kg/tree for trees with a dbh of 48-80 cm. Post-pruning leaf biomass was

similar to or higher than pre-pruning biomass in Watinoma and 20-40 percent lower in Dossi. In the same diameter classes, production differences between upland and bottomland sites within village locations were small, whereas they were more pronounced but not statistically significant between villages. There was a higher leaf production and a higher increase in leaf production per unit of crown area from one year to the next (thus also regrowth vigour) in Watinoma than in Dossi. This was primarily related to larger canopies in Watinoma, where pruning had been a more frequent and intense practice, despite similar trunk diameters. Leaf production per unit of crown area on upland sites in both years was slightly lower in the smaller diameter class than in the higher one, whereas both diameter classes had similar foliage yields per unit of crown area on bottomland sites. A second pruning after a year increases the ratio of foliage production to total (leaf and twig) production, especially in younger trees.

Leaf production data in *P biglobosa* are lacking, despite its good fodder properties. The species has high coppice shoot regrowth potential, with leaf production of 1.2 and 3 kg per tree at 8- and 16-week cutting intervals in 7-year old trees in the humid zone of Nigeria (Sabiiti and Cobbina, 1992). Based on litter collection baskets under four *V. paradoxa* (mean dbh 42 cm) and four *Bombax costatum* (mean dbh 39 cm) trees in Thiougou, southern Burkina Faso, leaf production was estimated at 29 and 23 kg per tree respectively (Bambara, 1993) or over 500 kg/ha based on local densities. Information on leaf production is lacking in many other parkland trees which are widely used in human diets, such as *Adansonia digitata*, *Cadaba farinosa*, *Celtis integrifolia*, *Crateva adansonii*, or as animal food such as *Acacia* spp., *Pterocarpus erinaceus*, *Pterocarpus lucens* and many others. More focus has been placed on the nutrient concentration and digestibility of foliage in tree species of the Sahel. Such information is reviewed in several places, including Le Houérou (1980) and Breman and Kessler (1995).

Fig. 6.4 Gum arabic oozing from an *Acacia senegal* tree, Barkedji, Senegal.
P. Danthu

Gum production

Several semi-arid African tree species produce gum. The most well-known species is *Acacia senegal* (commonly known as gum arabic). Estimates of gum production in this species vary, fluctuating between 0.1 and 1 kg, (maximum of about 10 kg in Sudan), and 0.25 kg in a highly stocked stand (von Maydell, 1983). A similar but inferior gum, tahl gum, is produced by *Acacia seyal*. *Sterculia setigera* also produces a gum which resembles the high quality gum karaya, derived from *Sterculia urens* in India, but information on production per tree is not available.

Wood production

Wood production data in semi-arid West Africa are relatively scarce, especially for parkland populations. This may be due to the fact that in past decades wood production schemes focused on plantations rather than parklands. Wood production may not be a primary objective of parklands, but this depends on species and farmers. Nevertheless, because time expenditure is a central concern in wood collection, the proximity of fields and fallows facilitates gathering and these locations can provide a significant share of wood used for fuelwood, tools and construction needs. Substantial quantities

Fig. 6.5 Wood gathered to build a drying rack for millet, Holom, northern Cameroon. ***C. Bernard***

of wood are made available when fields are cleared. It is also obtained from fallows, uncultivated woodlands, tree prunings and occasional tree felling in fields.

Data on annual (stem and branch) wood productivity in unprotected woody plant communities of West Africa with annual rainfall from 500 to 1 600 mm were first reviewed by Clément (1982) and expressed (WP in t/ha/yr) in relation to rainfall (R in mm) by the equation $WP = 0.05129 + 1.08171\ (R/1000)^2$. In West Africa, values range from 0.32 t/ha/yr for 500 mm rainfall to 1.61 t/ha/yr for 1 200 mm rainfall. Wood production is increased by a factor of 1.25 with protection against fire and grazing. Clément's curve appears to hold and is still used today (Bellefontaine *et al.*, 1997). As noted earlier, standing biomass and average plant height increase with improved soil conditions. Thus wood production is higher in bottomland locations (Breman and Kessler, 1995). As a percentage of total tree biomass, wood production decreases with increasing tree age and varies according to species.

There are isolated estimates of wood production in parkland trees. In parklands west of the town of Kano, northern Nigeria, average standing timber volume (cylinder estimated from tree height and dbh) was 0.56 m^3/tree or 8.9 m^3/ha, not including *Adansonia digitata* trees which have large boles of poor burning quality. Further away from Kano, timber volume was 9.5 m^3/tree and 108.5 m^3/ha in parklands with much larger trees and a lower density (Cline-Cole *et al.*, 1990). Most of these estimates of standing biomass were higher than those of surrounding uncultivated woodlands. Felling a *F. albida* tree provided 5-6 m^3 of fuelwood in Zinder (Lemaître, 1954, cited in Felker, 1978). When managed in 10-year rotations, *Acacia raddiana* yields 80 to 100 kg/tree in India (von Maydell, 1983). Standing wood biomass of parkland trees in southern Mali was estimated according to dbh using a volume curve established in a project for the inventory of forest resources in the country (Bagnoud *et al.*, 1995b). It ranged from 0.5 m^3 for trees in the 20 cm dbh class to 6.5 m^3 for trees in the 70 cm dbh class.

Figures of standing tree biomass/ha in parklands are often far higher than figures for woodlands and forests in various degrees of degradation and underline the potential of parklands as a major wood supply source. Survey data in Kenya revealed that the standing volume of woody biomass found within conventional forests, including both state-owned indigenous forests and forest plantations, is lower than the volume outside (Holmgren *et al.*, 1994).

Estimates of the annual wood production available for harvesting appear to vary according to calculation methods, as well as site productivity, density of woody species, and harvesting intensity. Based on projections of parkland density change over the next 50 years rather than measurements of harvested quantities, annual wood production was calculated at 0.15-0.2 m^3/ha with *V. paradoxa* and *P. biglobosa* densities of 9 to 17 trees/ha in Mali (Bagnoud *et al.*, 1995b). Because it is pruned more frequently and intensely, estimates are higher for *F. albida*. Jensen and Koné (1982, cited in Miehe, 1986) estimated that

harvestable wood in *F. albida* parklands with 40-60 trees/ha amounts to 1.8-4.7 m^3/ha according to rainfall and tree age in Senegal. Given a weight of 200 kg/m^3, this is equivalent to 360-940 kg/ha. Wood made available from total crown reduction of *F. albida* trees through pruning depends on tree diameter. In Burkina Faso, wood production was 30-40 kg for trees with dbh of 16-48 cm, and 80-130 kg for trees 48-80 cm in diameter, giving an overall average of 0.2-0.3 m^3 per tree. Taking into account local tree density and pruning intensity, production of pruned wood was estimated at 100-200 kg/ha/yr (Depommier, 1996a). With a 20-35 percent volume reduction, pruning of *F. albida* in an Ethiopian study site gave 0.4-0.5 m^3 per mature tree on a 4-5 year rotation, or about 0.1 m^3/tree/yr (Poschen, 1986). Compared with the apparent extent of parklands' use for wood procurement, there are few production data, especially for parkland species often cited for fuelwood or other wood uses, such as *Anogeissus leiocarpus*, *Acacia* spp., *Azadirachta indica*, *Balanites aegyptiaca*, *Combretum* spp., *Crossopteryx febrifuga*, *Diospyros mespiliformis*, *Guiera senegalensis*, *Pterocarpus* spp., *Prosopis africana* and *Tamarindus indica*.

Wood quantities to be harvested from parklands appear to play a significant role in farm needs. Wood consumption in rural areas is estimated at around 270-310 kg/person/yr for fuelwood (Ernst, 1978) and around 30-100 kg/person/yr for wood for tools and construction (März, 1986) or roughly 1 800 to 2 400 kg/yr for a family of six. As estimated by Depommier (1996a), a production of 100-200 kg/ha/yr from an average farm of 2 ha would cover at least 10-20 percent of the annual fuelwood needs of a local farm household. However, the thorough evaluation of parklands' contribution to overall household wood needs would require additional quantitative studies.

Species information regarding appropriateness for fuelwood, charcoal or construction use, indigenous knowledge and scientific evaluation of characteristics of fuelwood species are not reported here but can be found in a variety of references including Cline-Cole *et al.* (1990), von Maydell (1983) and Rocheleau *et al.* (1988).

Summary

Agroforestry parklands represent a major production site, not only in number but also in quantity, of non-timber forest products. Except for *Faidherbia albida* and *Vitellaria paradoxa*, the availability of data on fruit production is limited. Determined by a combination of genetic and environmental factors, yields vary substantially on an annual basis and between individuals of the same species. Potential production increases with size and, in *F. albida*, is heavily depressed by pruning. Given the high nutrient requirements of fruit, tree productivity depends on site conditions, as well as management practices, phenology and climatic patterns, which need to be defined more clearly.

Foliage production displays a lower variability between species, between individuals of the same species and between years than fruit production. Its proportion relative to standing biomass decreases with increasing tree age and size. Regular pruning of *Faidherbia albida* appears to have more impact on leaf production than site differences. Leaf production data in parkland species are limited and fragmented. Annual wood production in woody plant communities in West Africa is fairly well established and is favourably influenced by protection from fire and grazing, and soil fertility. Standing woody biomass of individual parkland trees is estimated at 0.5-10 m^3/tree, depending on tree size. At a national level, woody biomass in parklands can be significantly higher than in uncultivated woodlands due both to a higher standing biomass per hectare and to a larger surface area. Annual wood harvests in parklands may cover only a small part of household wood requirements but are significant because of their proximity.

SOCIO-ECONOMIC BENEFITS OF PARKLANDS

CHAPTER VII

Food security

It is estimated that up to 25 percent of the African population suffer from chronic food insecurity, receiving less than 80 percent of the recommended daily calorie intake (World Bank, 1989b). Even where calorie intake is sufficient, malnutrition may still arise caused by a lack of micronutrients and proteins. In West Africa, a 'lean season' commonly occurs at the end of the dry season and the beginning of the rainy season, when the previous season's stocks are exhausted and the current season's crops have not yet been harvested. Even if enough calories are available, people may still feel hungry if they are unable to obtain the requisite number from their preferred foods or those prescribed by their culture (Ogbu, 1973, cited in Schreckenberg, 1996). Hungry periods can also result from seasonal household expenses, such as taxes, school fees, or even resource outlays on such social events as funerals or festivities (Chambers and Longhurst, 1986).

The importance of forest and parkland products for home consumption and food security has been emphasized by a number of authors (e.g. Poulsen, 1982; Falconer, 1990). Schreckenberg (1996) reviewed ways of categorizing wild foods. They can be differentiated according to the parts of the trees being used or according to the purpose and intensity of use (collection for emergencies, regular consumption, gathering for sale, semi-cultivation or cultivation). They can also be grouped by type of edible products such as vegetables, fruits and nuts, condiments, beverages, and edible fats and oils. Data are presented here showing that parkland foods are important to people's diets and nutritional health both quantitatively and qualitatively and that they make a vital contribution to food variety as well as to achieving a seasonal nutritional balance.

Quantitative aspects of consumption

The annual consumption of products originating from parklands (fields and fallows) is far from insignificant. The products vary by ethnic group according to tastes and availability. Average consumption of *Vitellaria* butter is estimated to be about 10 kg/year/person, with slight variations according to author (10.9 kg by Coull, 1928; 7.6 kg by Fleury, 1981; 12.6 kg by SCETAGRI, 1983, cited in Hyman, 1991; and 10.3 kg by Schreckenberg, 1996). Citing a number of studies in Togo, Ghana and Nigeria, Campbell-Platt (1980) reported a daily consumption of fermented *Parkia* seeds (*soumbala*) of 1-17 g per person in West Africa. In central Benin, women reported using between 33g and 66g of *soumbala* per household per day or 7-10 g per person (Schreckenberg, 1996).

Fig. 7.1 *Parkia biglobosa* products: fermented '*soumbala*' (front), cleaned seeds (middle), yellow pulp (back).
K. Schreckenberg

Consumption of non-timber forest products (NTFPs) is not only high but also very common. In most of the southern Sahel and Sudan zones in Africa, *Vitellaria* butter is the most affordable and extensively used fat. In non-pastoral areas it is sometimes the only available source of fat for rural populations (Hyman, 1991; Masters, 1992). In Burkina Faso, *Vitellaria* butter is the only cooking oil consumed by 88 percent of rural households. It is also consumed regularly by 25 percent of urban households and at least twice a week by another 40 percent (SAED, 1989, in Crélerot, 1995). Further south or in the urban centres, other oils such as palm, groundnut and cottonseed oils are sometimes affordable substitutes. Nevertheless, in the Southwest of the country, surveys showed an average 84 percent of respondents using *Vitellaria* butter for various staple cereal dishes as compared with only 16 percent for other oils such as cotton, groundnut and sesame (Lamien *et al.*, 1996).

In Benin, 52 percent of people eat fermented *Parkia* seeds on a daily basis, and 85 percent do so in the North (Fandohan, 1983, cited in Schreckenberg, 1996). The Kabyé in neighbouring Togo consume *soumbala* on 90 days out of 100 (Perissé, 1958, cited in Campbell-Platt, 1980). In southwestern Burkina Faso, 60 percent of those interviewed used *soumbala*, compared with 32 percent using its commercial substitute, 'Maggi' cubes, as a seasoning for their meals (Lamien *et al.*, 1996).

The focus of the above data on only two species does not reflect the wide array of parkland species representing valuable (small or large) inputs to diets. This is due to the lack of readily available information on quantities consumed for both major and minor parkland products. *Adansonia digitata, Balanites aegyptiaca, Bombax costatum, Boscia senegalensis, Cordyla*

pinnata, *Tamarindus indica*, *Ziziphus mauritiana* are only a few examples of species for which systematic collection of consumption data would be necessary to better assess their importance for local food security.

Qualitative contribution of parkland foods

Not only do edible parkland products supplement the nutritional value of basic cereals in lipids, proteins, vitamins and minerals; they also diversify diets and enhance villagers' seasonal food balance since they become available at different times of the year.

Nutritional quality

Farmers possess an extensive knowledge about local food resources. The food values of products originating from common parkland trees presented in Table 7.1 suggest that these trees represent a very rich pool of food nutrients. Additional data on the nutritional contents of woody plants in the Ferlo region of northern Senegal are provided in Becker (1983).

Fig. 7.2 *Adansonia digitata* fruit: the pulp is used as a flavouring in a variety of cool and hot drinks.
R. Faidutti

Characteristics of traditional foods contribute, and are well adapted to, the physical health of local populations. For instance, both *Adansonia digitata* (baobab) and *Sterculia setigera* are excellent regulators of digestion. Baobab leaf powder contains pectins and hemicelluloses which prevent constipation and diarrhoea, and an exudate of *S. setigera* can absorb up to 250 times its water volume (Bergeret and Ribot, 1990). The 1: 4 ratio of phosphorus and calcium results in optimal absorption of both elements.

The value of tree and shrub leaves for human nutrition (rather than for fodder) has been neglected until recently, probably because scientific knowledge has accumulated in temperate regions where consumption of tree leaves is not common (Bergeret and Ribot, 1990). However, edible tropical leaves are much richer in calcium, phosphorus, iron and vitamins A, B, C and niacin than their temperate counterparts. Fruit and vegetables are the only source of vitamin C in diets. Leaves and fruit whose protein content ranges from 4 to 10 percent of fresh weight (1-2 percent for temperate vegetables) take on a critical significance when meat and fish are unavailable. The drying methods used by women also increase the protein content of the leaves. In the Sine Saloum region of Senegal, gathered foods provide 30-52 percent of calcium, 65-92 percent of retinol (precursor to vitamin A), 14-40 percent of B_2 vitamins, and 72-95 percent of vitamin C in the total intake (Bergeret and Ribot, 1990).

Crélerot (1995) found that in southwestern Burkina Faso, *Vitellaria* butter was the only source of fat in children's diets in all seasons. Being an energy-dense food

Table 7.1 Food value of some non-timber parkland products

Product	Proteins[a]	Lipids[a]	Glucids[a]	Calcium (mg)	Vit. A equiv. (mcg)	Thiamin Vit.B1[b]	Ribo-flavin Vit. B2[b]	Niacin[b]	Vit. C[b]	Phosph.[b]	Iron[b]	Kcal per 100g
Adansonia digitata												
-fresh leaves	4.0	0.3	14.4	395	-	-	-	-	42	67	25-50	69
-dry leaves	12.5-13.1	2.9	53.5	2266	4856	0.13	0.82	4.3-4.4	tr.c	261-66	25	279-82
-flour	2.3	0.1-0.3	75.6	293	20	0.38	0.06	2.16	169-270	96-118	7	280
Vitellaria paradoxa												
-fresh fruit pulp	1.9	1.2	21.7	-	-	-	-	-	-	-	4,7	94
-kernel	6.8	49	35.6	100	-	0.52	-	-	-	-	3	579
Detarium microcarpum												
-fruit pulp	4.9	0.4	81.8	82	-	0.03	-	-	32	84	1.8	310
Parkia biglobosa												
-dry fruit pulp	3.4	0.3-0.5	80.7	125	1200	1.1	0.7	1-3.03	255	164	3.6	310
-raw seed	43.6	21.8	32	233	-	0.54	-	-	6	503	11	432
-fermented seed	35	29	16.4	264	520	0.03	2.1	-	0	477	-	431
Saba senegalensis												
-fresh seed pulp	-	-	18.5	-	-	tr.	tr.	tr.	48	-	-	7
Sclerocarya birrea												
-kernel	30.6	-	0.5	0.17	-	-	-	-	-	102	-	-
Tamarindus indica												
-fruit	1.9-2.0	0.1-0.9	8.6-16.6	21-60	-	0.18	0.09	0.6	9	97-190	2.2	270
-leaves	14.1	3.5	56.2	230-506	-	-	-	-	-	22	-	73
Ziziphus mauritiana												
-fresh fruit pulp	1.9	tr.	25.2	51	-	tr.	tr.	tr.	66	20-86		93
-dry fruit pulp	4.3	0.2	75.4	210	0	0.03	0.02	2.1	24	56		286

Source: Data from Bergeret and Ribot (1990); Pasco (1990): presented in Lamien *et al.* (1996)
Notes:
[a] grams per 100g
[b] mg per 100g
[c] tr. = trace

and given children's small stomach capacity, its consumption probably resulted in higher energy intake as well as enhanced absorption and transport of fat-soluble vitamins such as vitamin A, which is often deficient among preschool children in Burkina Faso. *Parkia biglobosa* seeds supply lysine, the main amino-acid which is generally lacking in millet and sorghum (Campbell-Platt, 1980). Additional details on the composition of pulp and seeds at various stages of preparation are available in Hall *et al.* (1997). The average vitamin C content of the pulp of baobab fruit is over 2 500 mg/kg, which also helps to maintain low blood pressure, enhance immunity against tropical diseases and reduce incidence of cataract development and coronary disease (Sidibé *et al.*, 1996). In Sine Saloum, Senegal, kernels of *Cordyla pinnata* are consumed as a substitute for meat (Niang, pers.comm.).

Food variety

An important dimension of the contribution of parkland foods is the dietary diversity they provide. Abundance of carbohydrate-rich foods alone does not ensure nutritional well-being; proteins, fats and micronutrients are also necessary. It is common, however, as observed in southwestern Burkina Faso, for children's diets to have the opposite characteristics (Crélerot, 1995). Limitations and irregularities in food variety make young children vulnerable to nutrient deficiencies. Foods derived from parklands and forests help this situation, but may not be systematically recorded because of their occasional use.

Their importance is illustrated by the large but variable number of species surveyed in agroforestry parklands. In the Ferlo region of Senegal, 80 percent of existing woody plants have edible parts, but only about 25 species are widely consumed (Becker, 1983). A total of 105 wild plant species, including herbaceous and aquatic plants, tubers and mushrooms as well as honey, are collected by villagers of Kumbija, Senegal. These plants yield one or a number of edible gathered foods. Over two-thirds are trees, shrubs and lianas, which come from both parklands and village forests (Bergeret and Ribot, 1990). Consequently, biodiversity conservation in parklands has important food security implications.

Fig. 7.3 Flowers and calyces of *Bombax costatum* used for making a glutinous red sauce. *K. Schreckenberg*

Seasonal food balance

Parkland foods contribute to a steady supply of food throughout the year. Their availability in the dry season and the early part of the rainy season, which relates to the flowering, leafing and fruiting stages of parkland species, helps to overcome the 'lean season' mentioned above. Farmers often depend on edible parkland products to replace the missing or insufficient staples at this time. Crélerot (1995) reported wild leaves such as guinea sorrel (*Hibiscus sabdariffa*) and baobab replacing garden-grown vegetables and leaves, which were unavailable in the pre-harvest season, in the diets of young children in Djebenao and Dimolo, southwestern Burkina Faso. Fruit consumption was reported in 35 percent of children in the pre-harvest season as compared with 16 percent in the post-harvest season when food availability increases.

Parkland food products also provide the necessary energy for field cultivation and harvest operations. This may be especially true of fruit. *Vitellaria* fruit, for instance, were consumed by all villagers at any time of the day in Djebenao and Dimolo and supplemented the limited meals available during the seasonal food shortage. Because fruit, and snack foods more generally, are consumed outside meals, their contribution to diets is difficult to establish, but often particularly significant.

In some areas, tree products are not just consumed during periods of food shortage but even provide the main staple food or a regular supplementary part of the daily diet. While *Adansonia digitata, Balanites aegyptiaca* and *Ziziphus mauritiana* are the most appreciated trees in the Ferlo region of Senegal, and provide supplementary foods, *Boscia senegalensis* fruit and the leaves of *Cassia obtusifolia* (herbaceous plant) make up the main part of Peulh meals (Becker, 1983). In areas of Mali, porridge made from *Boscia senegalensis* is combined with the limited stores of millet in poorer households (Martin, 1985).

In order to tide them over seasonal scarcity, women process substantial stocks of collected food items for storage to allow them to spread their use over the whole year. Many products lend themselves well to storage over several months or a year after drying or some processing. *Vitellaria paradoxa* nuts and butter, *Parkia biglobosa* seeds or *soumbala*, palm oil and palm kernel oil, as well as *Bombax costatum* calyces, dried

and powdered baobab leaves, and tamarind pods can be kept for several months. While these stocks are not usually visible, they are significant in diversity and size. In Senegal, Bergeret and Ribot (1990) reported that women had stocked several hundred kilograms of products from over ten species. Fleshy fruit and fresh leaves are an exception as their use is restricted by their seasonal availability.

Forests have traditionally provided food and marketable products during emergency periods of illness or famine. The same is probably true for parkland resources. Elders tell of famines which villagers survived by spending time in the surrounding forest harvesting wild plant foods, honey and bushmeat. They also complain that the availability of resources has declined due to overuse and degradation in recent decades. In years of low agricultural production, a greater number and larger quantity of gathered products are sold (Bergeret and Ribot, 1990).

Parklands have traditionally provided food and marketable products during emergency periods of illness and famine.

The seasonal availability and high food-security and income value of most NTFPs have direct consequences for women's allocation of time. The agricultural slack period provides extra time for women (and men) to engage in collection, processing and marketing activities, and off-season markets are generally more active than during the growing season (Guinko and Pasgo, 1992). Even when NTFP-related activities conflict with work in the field, as is the case with the gathering of *Vitellaria* nuts which occurs during the early part of the agricultural season, women try to find ways to devote time to them. They may hire labour, interrupt or reduce their time spent on other income-earning activities, or seek temporary release from their responsibilities in family fields.

Health care

Parklands and forests are essential components of traditional medical systems in semi-arid West Africa. For common illnesses rural dwellers rely mainly on remedies based on plants found in forest lands surrounding their villages; for more serious diseases, they may see local specialists who use a combination of drugs and herbal medicines (Emerton, 1996). There is abundant literature illustrating the variety of woody species exploited for medicines. In Mali, two-thirds of the 100 tree species available in the Monts Mandingues Forest near Bamako are used by villagers for pharmaceutical products (Sow and Anderson, 1996). Moreover, according to resource people from the local Traditional Healers' Association, all inventoried species have a use in traditional healing although some villagers do not know the uses of all of them. On Ouagadougou markets, some 99 species producing traditional medicines were recorded (Fernandez de la Pradilla, 1978). Most of them were woody species.

There is a large amount of information on which species are used for particular medicinal treatments. References to medicinal applications of parkland species such as *Annona senegalensis*, *Daniellia oliveri*, *Ficus* spp., *Hymenocardia acida*, *Khaya senegalensis* and *Tamarindus indica* are presented in Depommier and Fernandes (1985). Among numerous medicinal properties reviewed in Hall *et al.* (1997), the bark of *P. biglobosa* is used to treat infectious diseases and ailments of the digestive system, its leaves are used for wounds and skin ailments, the roots are used against epilepsy and the pulp as a febrifuge. Medicinal uses of *Vitellaria* butter are summarized in Hall *et al.* (1996). The bark of *F. albida* trees is used for the treatment of coughs (Depommier, 1996b). Major medicinal uses of numerous Sahelo-Sudanian species are listed in von Maydell (1983) and can be found in various regional floras (Dalziel, 1937; Aubréville, 1938; Berhaut, 1954; Irvine, 1961; Kerharo and Adam, 1974).

The contribution of parklands to the production of traditional medicines obtained from the 'forest' is not completely clear. Many forest species with medicinal properties are also found in various frequencies in agroforestry parklands. However, traditional herbalists report that the medicinal properties of some species are higher when found in the wild than in cultivated areas. The decreasing availability of medicinal tree resources may be an additional motive for the maintenance of given species in fields. Information gaps identified by Falconer (1990) in her review of the use of forest resources in traditional medicine in the West African humid forest zone also apply to the drier zone of parkland occurrence. These include the need to:

- Assess the extent to which treatments based on forest products are used (past versus present use; species ranking in importance; specialist/non-specialist use patterns, etc.).
- Gather indigenous knowledge on (time, location, etc.) patterns for the proper collection, production and use of medicinal products.
- Carry out chemical and pharmacological studies on plant material as it is used traditionally (in combination with other species, processing, etc.).
- Test and evaluate the effectiveness of traditional medicines.
- Assess the value of traditional medical systems in terms of the costs of modern health care practices.

Economic importance of parkland products at the local level

Diversity of products

Parkland trees are excellent 'multi-purpose' species. *Adansonia digitata*, *B. aethiopum*, *P. biglobosa*, *T. indica* and *V. paradoxa* are particularly remarkable in the large number of end-use products they provide. In the case of *B. aethiopum* at least eight different parts of the tree are used for different purposes. Both the nut and mesocarp of the fruit are consumed fresh by children and adults. The seedlings are widely traded. The trunk offers one of the best all-purpose woods. The leaves are used as fencing and roofing material. The petioles are used as fuelwood and for furniture-making. Fish-traps ('*nasses*') are woven from the leaf fibres and roots. The terminal buds are used to tie up bunches of millet and sorghum and the male flowers make an excellent fodder. Table 7.2 gives a general

Fig. 7.4 Tamarind pods and balls of pods with the husks removed for storage and sale. *K. Schreckenberg*

Table 7.2. Products and uses of common parkland trees

Species	Uses
Acacia raddiana	Pods, leaves and young shoots as fodder; excellent fuelwood and charcoal, poles, utensils; bark as tannin; bark and roots as rope; dune fixation; leaves and bark as medicine.
Acacia senegal	Gum arabic traded internationally and used locally in foods, medicine and craft; excellent fuelwood, poles and utensils; nitrogen fixation; leaves and pods as fodder; honey; dune fixation.
Adansonia digitata	Fruit pulp in drinks and porridge; seeds for sauces; leaves and seedlings as vegetables; flowers eaten fresh; young leaves as fodder; bark for rope and basketry; wood as mulch; roots for red dye; fruit and leaves as medicines.
Anogeissus leiocarpus	Good timber; excellent fuelwood and charcoal; leaves for yellow dye; fruit and sepals for sauces; gum in local foods.
Azadirachta indica	Wood for poles, construction, tools; leaves as fodder for goats and camels; fruit as famine food; seeds yield oil used for soap; oil cake as insecticide; medicines.
Balanites aegyptiaca	Seeds for oil, soap; seed flour as a famine food; leaves and young shoots in sauces; leaves and fruit as fodder; excellent fuelwood and charcoal, utensils; bark, leaves, fruit and oil as medicines.
Bombax costatum	Kapok fibre from capsules; wood for utensils and canoes; calyces for sauces; dried young fruit eaten; medicines.
Borassus aethiopum	Nut and mesocarp of fruit consumed fresh; seedlings as vegetables; sap for wine; trunk as all-purpose wood; leaves for fencing and roofing material; petioles as fuelwood and for furniture-making; leaf fibres and roots for nets; male flowers as fodder; medicines.
Cordyla pinnata	Green fruit in sauces; ripe fruit eaten fresh or in jams; good fuelwood and charcoal; timber; medicin
Diospyros mespiliformis	Fruit eaten fresh or dried and in drinks; honey; leaves as fodder; good fuelwood, charcoal, and timber; leaves, bark and roots as medicines.
Faidherbia albida	Leaves and pods as excellent fodder; soil amelioration; wood for utensils; bark, leaves, fruit and gum as medicines.
Ficus sycamarus	Leaves in soups; fruit consumed fresh, in sauces and in wine; fruit and leaves as fodder; wood for tools; leaves, bark and latex as medicines.
Hyphaene thebaica	Mesocarp of fruit eaten; pericarp and kernels as famine food; seedlings as vegetable; leaves for rope, basketry, brooms and nets; wood for timber and blacksmiths' charcoal.
Lannea microcarpa	Fruit eaten fresh or in drinks; leaves as fodder for goats; edible gum; bark and leaves as medicines.
Parkia biglobosa	Pulp of pods eaten fresh or in drinks; fermented seeds as spicy seasoning widely used in sauces and sometimes processed as stock cube; leaves, bark and roots as medicines; tannin in bark.
Prosopis africana	Seeds fermented as condiment; fruit and leaves as fodder; excellent fuelwood and charcoal; timber; all parts as medicines; soil amelioration.
Pterocarpus erinaceus	Leaves as excellent fodder; wood as timber, poles, furniture and charcoal; colouring from bark and roots; tannin in bark; medicines.
Sclerocarya birrea	Fruit eaten fresh or in drinks; seeds yield oil and can be eaten; ash used in cloth dyeing; bark as fibre; gum as ink; wood for utensils; bark, leaves and roots as medicines.
Sterculia setigera	Edible gum (sauces); seeds are eaten; bark fibre as mats and rope; fuelwood; bark and leaves as medicines.
Tamarindus indica	Roasted seeds are eaten; fermented pods as sweet and acidic flavouring in sauces and drinks; leaves and flowers in soups and sauces and as fodder; wood for utensils; all tree parts as medicines.
Vitellaria paradoxa	Fruit eaten fresh; kernels processed for production of butter used as cooking oil and cosmetic, exported for production of cocoa butter equivalent; excellent fuelwood and charcoal; butter, roots and bark as medicines.
Vitex doniana	Fruit eaten fresh and in drinks; leaves in sauces; bark and roots as colouring; construction wood; medicines.
Ximenia americana	Fruit eaten fresh or in drinks; seeds yield oil for cooking, illumination and for softening leather; tannins in roots and bark for leather treatment; fuelwood and charcoal; medicines.
Ziziphus mauritiana	Fruit eaten fresh or dried, in drinks; dry pulp as flour for bread; leaves as vegetables; fruit and leaves as fodder; tannin in bark; wood for furniture, utensils and fuelwood; medicines.

indication of the large array of uses derived from key parkland species. More detailed information on these and additional species can be found in Bergeret and Ribot (1990), Booth and Wickens (1988), von Maydell (1983), Raison (1988) and Rocheleau *et al.* (1989).

Market volume and income

Beyond contributing to food security, parkland/forest products are an important source of local income-generating activities. This is reflected in several parameters including their diversity and quantity sold on local markets, the number of people involved in marketing, and measurements of NTFP-related income.

Unfortunately the relevant parameters have been insufficiently studied for the majority of parkland species. For instance, von Maydell (1983) noted that gum harvests from *Sterculia setigera* in Senegal amounted to 50 000t/yr in the 1970s, but the proportion of gum commercialized is unknown. Some 200 000 tons of *P. biglobosa* seeds are collected every year to be processed in northern Nigeria (Ferre, 1993). Other examples of commercialized products include *F. albida* pods as fodder, *Bombax costatum* (kapok) fibre for stuffing cushions and mattresses, palm wine, a large array of wooden agricultural and domestic tools, *Adansonia digitata* and *Pterocarpus erinaceus* foliage for human and animal consumption respectively, and a variety of oil-yielding species such as *Balanites aegyptiaca, Elaeis guinensis, Parinari macrophylla* and *Sclerocarya birrea*.

For those involved on a seasonal basis, parkland products marketed locally may be the source of important income to cover annual expenditures, savings and loan repayments.

There is a large diversity of NTFPs sold on local markets, often derived from a smaller number of key species. Schreckenberg (1996) recorded up to 42 NTFPs originating from 16 parkland tree species in markets in the Bassila area in Benin. A total of 26 different edible products from 16 parkland and forest species were inventoried in markets of Zitenga and Yako, Burkina Faso (Nikiéma, 1996). Similarly, 30 products from 17 woody species were identified in markets in southwestern Burkina Faso (Lamien *et al.*, 1996). In spite of the great diversity of NTFPs available, the total value of NTFPs sold at markets may be dominated by just a few main products or species. Only *P. biglobosa* seeds, *A. digitata* leaves, *Bombax costatum* calyces, *V. paradoxa* kernels and butter as well as honey were sold regularly in Zitenga (Guinko and Pasgo, 1992). In the villages of Diepani and Kodowari, Benin, products from *V. paradoxa*, *P. biglobosa* and the oil palm accounted for about 90 percent of the annual NTFP value of the markets (Schreckenberg, 1996).

As has also been shown for humid zones such as southern Cameroon (Ndoye *et al.*, 1997), commercial activities involving forest products are economically significant in parkland zones. This is evident in a number of studies which have used variables such as market transactions, sales per merchant, proportion of individual or household income or expenses covered by NTFP income, as well as national income. Unfortunately data in the literature are often presented in a non-standardized way, making comparisons difficult. The total value of such items sold on an average market day in Zitenga, Burkina Faso, amounted to 232 000 FCFA (Guinko and Pasgo, 1992). The annual value per vendor of products sold from the three main species was between US$200 and US$397 in markets of southwestern Burkina Faso (Lamien *et al.*, 1996). On three markets in Bamako, Mali, the sale of *Pterocarpus erinaceus* fodder generated revenues of US$6-11 per vendor per day, which was estimated to represent 3-5 times the average earnings of a labourer in this area (ICRAF, 1996). Income from *Borassus aethiopum* products amounted to 182 000 FCFA in 20 villages of the Cayor area of Senegal (Projet Roneraie Cayor, 1992).

Additional data on the income provided by several parkland species are presented in Ounteni (1998). The weekly sale of *miritchi*, *B. aethiopum* seedlings (cooked as a vegetable), on the markets of Kamba and Gunki, Nigeria, amounts to 1.5 and 1.2 million FCFA respectively, or 33 million FCFA over the three-month production period. Net gains from the production and sale of chairs, beds, tables and stools made from the petioles of *B. aethiopum* over a 14-month period reached 384 000 FCFA in Niger. In the southern Boboye area of the country, the economic value of the (increasingly depleted) *Hyphaene thebaica* palms is such that hundreds of women migrate to the area for three to four months during the dry season to participate in the collection and sale of fronds and woven mats. On the Birni N'Gaouré market, the income of migrant women collectors from *H. thebaica* fronds represents over 12 million FCFA per year. Fronds are also transported further south and sold on the Gaya market, where they provide 25-50 million FCFA/yr to women collectors. Finally, some 800 to 1 500 mats worth 200-2 000 FCFA each are sold daily in Gaya (Ounteni, 1998).

Several authors have assessed the contribution of parkland or forest products in sustaining women's, household and village economies. In a village of The Gambia in 1988-1989, one-third of total income earned by individuals originated from the collection of forest products (Madge, 1995). Income from tree crops and forests represented 23 percent of total household income in Sierra Leone (Davies and Richards, 1991), while indigenous tree crops provided 25-50 percent of total cash income during a season in eastern Nigeria (Lagemann, 1977).

Most women in the Bassila region of Benin engage in a number of activities to cover their regular weekly expenditures (estimated at 500-2 600 FCFA for sauce ingredients, grain milling, and snacks and meals). Schreckenberg (1996) found that regular NTFP-based activities (e.g. the sale of *V. paradoxa* butter or *P. biglobosa soumbala*) are not highly remunerative but that their contribution is of a similar order of magnitude to other non-NTFP enterprises, and can cover about 10-20 percent of these weekly expenses. However, such year-round activities are often undertaken by only a few specialized women. In contrast, seasonal NTFP-based activities, such as the sale of *V. paradoxa* kernels or palm oil and the resale of honey, can cover the cost of women's additional annual expenditures (estimated at 10 000 FCFA for clothes and pots). In this area, the only tree-related enterprise that could completely cover a man's cost of living was palm wine tapping combined with the distillation of palm spirit. Other male activities, such as the collection of palm nuts, honey, *Saba florida* (sponges) and *Zanthoxylum zanthoxyloides* (spice), could provide 5-60 percent of annual income but could not replace agriculture as the principal source of income. Overall, in the three villages studied, all households were involved in the collection of *Vitellaria* kernels. In addition, two-thirds of households had at least one member earning an income from another forest product. Average annual earnings from forest products collected and processed for sale (excluding home consumption, bushmeat, wild herbs and wood) amounted to about 6 000 FCFA per person (Schreckenberg, 1996).

In southwestern Burkina Faso, the average annual cash income from processed or unprocessed *Vitellaria* nuts was US$15-35, but dropped to US$6 in a very low production year (Crélerot, 1995). According to references cited by Crélerot, *Vitellaria* nut activities can represent 20-60 percent of women's income in rural areas. Annual returns from the sale of *P. biglobosa* products were estimated at 26 800 FCFA or about 26 percent of farmer income in Burkina Faso, and about 21 percent in Nigeria (Teklehaimanot *et al.*, 1997). In the Upper Niger River Valley region of Mali, Grigsby and Force (1993) reported that forest products were the most important source of income (greater than market- and agriculture-related activities) used by women to replenish their informal savings and repay their

Box 7.1
Opportunities for growth in the domestic market for Vitellaria paradoxa

There are indications of high local demand and renewed interest for *Vitellaria* on domestic markets. In Ghana, Adomako (1985) forecast that, based on high prices in the South, local demand was likely to remain high and to absorb a greater proportion of production if it increased. Bliss and Gaesing (1992) also noted that, due to the high demand for *Vitellaria* kernels in Côte d'Ivoire to be processed industrially for the export market, young men were competing with women for nut collection. The January 1994 devaluation of the CFA franc led to inflated prices for imported oil crops and changed domestic demand in the sub-region. Côte d'Ivoire, for example, reduced exports of palm oil in favour of using it in domestic soap and cosmetic manufacture. As a result, palm oil users in Burkina Faso (mostly soap producers) are now looking into using *Vitellaria* products as a substitute. CITEC (*Compagnie industrielle du textile et du coton)* and SOFIB, the two major oil-producing companies, have exported hardly any *Vitellaria* in the past few years, supplying it instead to domestic soap manufacturers. Likewise, Côte d'Ivoire purchases fairly large quantities of *Vitellaria* products from Burkina Faso, and the fact that its exports do not increase may mean that *Vitellaria* imports are being used internally. Several small-scale enterprises (e.g. CINTEC – *Compagnie internationale de négoce en transport et commerce*) in Burkina Faso are also setting up processing facilities for *Vitellaria* and other oil crops to supply the national and sub-regional markets.

Vitellaria products as a food item are far from having reached their optimum level of domestic development. Given the importance of local consumption of the butter in West Africa and the oil in East Africa, the potential probably exists for developing cheap, stable and odourless packaged industrial products for local markets. *Vitellaria* fruit could also be marketed on a wider scale over a longer period than is currently available. Many questions regarding demand (as well as supply) in these markets are worth studying in producer countries: What amounts and types of products should be developed? How should they be priced in relation to competing products? What kind of storage and packaging are appropriate?

informal loans. In Côte d'Ivoire, 16 percent of village production (for home consumption and sale) excluding livestock production originated from parkland products, particularly *P. biglobosa* and *V. paradoxa* products, wood handicrafts and fuelwood. Income from small game was higher than cotton income (Bernard *et al.*, 1996). In Fandène, Senegal, farm income from *B. aethiopum* products is higher than from all other sources including agricultural crops. The number of *B. aethiopum* and *Mangifera indica* trees are a main criterion determining household levels of wealth (Freudenberger, 1993b).

Finally, national income from 35 edible or medical forest products was estimated at US$6.5 million in 1979 in Senegal, of which gum arabic and *Ziziphus mauritiana* were the most important in the northern region (Direction des Eaux, Forêts et Chasses, 1979, in Becker, 1983). As illustrated in Box 7.1, far from declining in importance, there may still be significant opportunities for products such as *Vitellaria* to increase their share of domestic markets.

Parkland products of international economic importance

Two parkland commodities are internationally traded and have a high national significance for several Sahelian countries because of their export earnings. These are gum arabic from *Acacia senegal* (also *A. seyal*) and *V. paradoxa* kernels sold for processing into a vegetable fat.

Gum arabic

Gum arabic is a water-soluble exudate, 95 percent of which derives from *A. senegal*, with the remaining 5 percent harvested from *A. seyal* (gum talha) (Seif el Din and Zarroug, 1996; Hulse, 1996). In water the gum forms a colourless, tasteless and odourless aqueous solution of up to 50 percent concentration. It is mostly used in the food industry in the production of dried soups, sauces, and dessert and cake mixes, as well as confectionary pastilles. It acts as an emulsion stabilizer and binder in pharmaceutical, cosmetic and other industrial products such as adhesives, textiles, printing, lithography, paints, paper sizing and pottery glazing.

This product was first used in ancient Egypt in paints and for embalming about 3 000 B.C. In the last two decades, it has been mainly produced in Sudan (70-90 percent), Senegal, Nigeria and Mauritania, with global annual exports of 20-50 000 tons. The crude exudate is sold for 8-10 times less than the US$15-25/kg paid for high-quality refined gum arabic suitable for food uses. In Sudan, the Gum Belt, where *A. senegal* is the dominant component of the woody vegetation, is the main producing area. It includes most of Kordofan and Darfur states and parts of White Nile state. In this country, the gum arabic market is regulated by the government with fixed annual prices and a monopolistic marketing structure.

Vitellaria paradoxa

General description

In Africa, *Vitellaria* is primarily used as a source of cooking fat. Within its range in the southern Sahel and Sudan, it is probably the most affordable, available and extensively used oil (Lamien *et al.*, 1996). It is also an important source of fat for making soap and may be used as a skin moisturizer. The fat is made from the kernels found when the dried nuts are cracked open. Due to different proportions of stearin (solid) and olein (liquid) in the fat, the West African subspecies *paradoxa* gives rise to a solid fat or 'butter' while the East African subspecies *nilotica* produces a liquid oil. The fruit flesh around the nuts is also very tasty and much *Vitellaria* fruit is collected to be consumed fresh and sold in Sahelian cities and along roadsides. Other local uses include for lighting, waterproofing of housewalls, and protection against termite damage, as well as its cultural and religious roles. *Vitellaria* butter also has numerous traditional medicinal applications as a balm for rheumatic pains, wounds, dislocations, swelling, bruises and skin problems.

Fig. 7.5 Various commercial items manufactured by Phycos, a local company in Burkina Faso specializing in cosmetic products made from *Vitellaria* butter.
R. Faidutti

Besides their local use, *Vitellaria* kernels have been traded for a century to countries in the North. They are an important source of export earnings for Sahelian economies, being the third largest

export of Burkina Faso in the 1980s (World Bank, 1989a). Annual exports to Europe are about 40-75 000 tons, with another 10-15 000 tons sold to Japan (Savadogo *et al.*, 1998). Besides a relatively small international cosmetic market, the vast majority of *V. paradoxa* production is directed to the food industries, particularly chocolate manufacture. The main actors in this market are a few multinational corporations, namely Vandemoortele, Unilever TPS, Aarhus and Karlsham. Due to its similar fat composition and particularly its high proportion of mono-unsaturated symmetrical triglycerides, *Vitellaria* butter is used as a cocoa butter equivalent (CBE) in chocolate products. Its stearin fraction is mixed with other vegetable fats such as palm oil and illipe (an Asian tree crop) to form a product of similar chemical composition to cocoa butter. Its olein fraction is used for margarines and baking.

The high triglyceride content of *Vitellaria* butter gives it a rich consistency which is valuable for cosmetic applications because of its hydrating, protecting and softening properties. While the unsaponifiable content is less than 1 percent in most other vegetable oils, the high percentage in *Vitellaria* (over 8 percent) imparts various properties including good penetration, wound healing, relief for dry, irritated skin, dandruff, chapping and ulcerations, as well as protection against the sun. A variety of companies in Europe and Africa market skin cream and sun lotion preparations based on *Vitellaria* butter. African examples include Phycos in Burkina Faso and SEPOM in Mali.

Market constraints

Actors in the *Vitellaria* market recognize that it is a narrow and 'confidential' market. Information needed to analyse this market including prices, purchased quantities, demand, etc., is 'strategic' and difficult to obtain and validate. This runs counter to the development and optimization of the resource (Brun, 1996). The following facts have been gleaned from studies by Terpend (1982), Saint-Sauveur and Simon (1993), Audette (1995), APROMA (1995), Savadogo *et al.* (1998), and UNIFEM (1997). International demand for *Vitellaria* for food purposes has declined in recent years. First, the demand for chocolate products (with up to 15 percent *Vitellaria* butter) in Eastern Europe has fallen off due to economic difficulties. Secondly, industries tend to build up large stocks in favourable years in order to ride out annual fluctuations in supply and demand. Most importantly, *Vitellaria* prices are linked to the production and price of cocoa. In years of poor cocoa harvest a good price is offered for *Vitellaria*, while the opposite is generally true in good cocoa years. Between 1985 and 1992, *Vitellaria* prices declined in concert with those of cocoa until they were equal in 1992. Since then cocoa prices have risen, but the impact on *Vitellaria* prices had not yet been felt at the time of Audette's report (1995). *Vitellaria* demand also depends on other CBEs such as illipe and fractionated palm oil, and to some extent palm kernel, cotton and soya oil, as well as on competition with components resulting from technological developments such as mechanical fractionation and enzymatic synthesis. Finally, the irregular supply and low product quality offered to export markets is not conducive to increased industrial demand.

International market opportunities

Market conditions in future years are difficult to predict, but there appears to be potential for improvement, particularly if progress is made on the regulation of CBEs of which *Vitellaria* is considered the best. The use of CBEs in chocolate production has so far been regulated at the national level. Their use up to 5 percent of content is currently allowed in the United Kingdom, Ireland, Scandinavia,

Switzerland, Austria, Portugal, Japan and the United States. In Eastern Europe the limit is 15 percent, above which the taste of the chocolate is altered. In contrast, the use of CBEs in chocolate is illegal in France, Belgium and Luxembourg, but cocoa butter replacers (CBRs) are permitted for coating products which do not strictly carry the name of chocolate, such as confectionery and cakes. Other European countries partially authorize it. The European chocolate industries would like to see the 5 percent norm extended to the whole of the European Union for technical reasons. The addition of *Vitellaria* CBEs in this proportion limits the surfacing of white fats when storage temperatures vary, gives increased shine and

Box 7.2

Cosmetics sector demand for Vitellaria paradoxa

The use of *Vitellaria* butter in cosmetics is expanding rapidly. While current demand is around 200 tons, the potential demand for *Vitellaria* for cosmetics products has been estimated at a maximum of 1 500 tons a year worldwide (Brun, 1996). This represents a minor part of the total market but it should not be ignored. The potential of the European cosmetics market was analysed by Saint-Sauveur and Simon (1993).

About half the demand of the cosmetics industry is supplied by food processing industries at a price twice that for food applications. However, price comparisons are not straightforward because the nature of the two products and the quantities used in the two sectors are not similar. The main advantage of *Vitellaria* butter for cosmetics is its high content of unsaponifiables. Natural variation in the proportion of the unsaponifiable fraction in kernels ranges from 3 to 17 percent (Gasparri *et al.*, 1992) and can be taken advantage of in the selection of high content varieties. Unsaponifiable content also appears to decrease with kernel maturation (Heilbron *et al.*, 1949, cited in Hall *et al.*, 1996). If the cosmetics destination of kernel supplies were known in advance, early harvesting resulting in kernels with a higher unsaponifiable content could be planned. The development of the cosmetics sector may benefit, therefore, from product differentiation starting in the early stages of production.

Another area in which progress could be made is in the manufacture of the butter. The refining process used by agro-industries has the advantage of stabilizing the butter, which is naturally high in unsaturated fatty acids and thus easily oxidized and very unstable in emulsions. Its disadvantage is that it also leads to a drastic reduction in the unsaponifiable fraction. This has prompted a number of cosmetics companies to obtain their butter from manufacturers of *Vitellaria*-based cosmetics derivatives or directly from African processors. However, difficulties in working with this pure and often less stable product have led to the incorrect perception that the refining process is necessary to ensure butter stability.

The lack of information about technological constraints and opportunities has been detrimental to the development of the *Vitellaria* butter market. Moreover, the lack of agreed quality standards, the unpredictable nature of the supply, and the high price of the butter have discouraged potential cosmetics users. In response, some actors have become more involved in the production stages. There is a growing interest among end users of *Vitellaria*-based products for direct partnerships with African suppliers and processors in order to obtain butter with well-defined technical characteristics. The transfer of some processing stages to Africa should be encouraged as it would allow the producing countries to offer a more elaborate product at a higher price and the cosmetics firms to buy the butter more cheaply. The development of supply and processing networks adapted to the specific needs of the cosmetics sector seems essential.

The dissemination of scientific data on *Vitellaria*'s properties to professional partners and further research into its active ingredients, together with the definition of widely-accepted quality standards for different types of processing would also help *Vitellaria* achieve a more significant place in the cosmetics sector. Given the multifaceted ecological and socio-economic roles this tree has traditionally played in Africa, the current demand among consumers for natural products produced in environment-friendly ways can be abundantly satisfied.

hardness at room temperature, and raises the fusion point so that the chocolate does not melt on fingers even in hot climates. The use of CBEs could expand geographical destinations and extend the chocolate season by a few weeks in the Mediterranean countries of the European Union, where the market for chocolate confectionery is growing fastest (Hall *et al.*, 1996). European chocolate consumption has doubled from 1980 to 1994, with the largest share in coated products which contain CBEs.

Côte d'Ivoire and other cocoa-producing countries have opposed this proposal, estimating that it would cut cocoa demand by 100-200 000 tons. However, producers of CBEs, and *Vitellaria* in particular, claim that the effect will not be detrimental to cocoa-producing countries, some of which are also producers of *Vitellaria*. In comparison with pure cocoa butter, the use of CBEs provides functional advantages which could lead to an expansion of markets. Meerschoek (1994, cited in Hall *et al.*, 1996) suggests that a maximum of only 3 percent of the annual global harvest of cocoa beans would be displaced.

Another potential growth area for *Vitellaria* products is the cosmetics sector as outlined in Box 7.2. In both this and the food sector, European industries would prefer to import *Vitellaria* butter already processed on-site rather than kernels to reduce transport and processing costs as well as adding value locally. Currently, two large factories exist in the region: Trituraf for Unilever TPS in Côte d'Ivoire and Nyoto in Lomé, Togo. However, they consider that local capacities for quality control are currently insufficient and that techniques for transporting butter without quality loss are not yet fully mastered (Brun, 1996). More in-depth analysis of demand and additional experiments with local processing may therefore be needed to ascertain the potential of local butter production for export.

Social differentiation in NTFP activities

Collecting

Collecting tasks are generally divided by gender. In the Bassila area of Benin, men's collecting activities, primarily for palm nuts, *Parkia* pods and honey, tend to require skill and involve risk (Schreckenberg, 1996). In contrast, women do not consider walking, collecting and carrying *Vitellaria*, tamarind, baobab and *Bombax* products as very laborious. Older women who may not be fit enough for other income-generating activities show an active interest in the gathering of these parkland products. In Cayor, Senegal, all collection/extraction activities on *B. aethiopum* are carried out by men, whereas the commercialization is undertaken by women (Projet Roneraie Cayor, 1992). Some products are exclusively gathered by children, such as *Vitex* and *Diospyros* fruits for sale at the market or to neighbours in Benin (Schreckenberg, 1996), or *A. digitata* fruit in Kumbija, Senegal (Bergeret and Ribot, 1990).

The fact that collecting parkland products requires no cash investment is a strong incentive for poor segments of village populations for household and commercial use.

In Mali, fuelwood and food items including leaves, nuts and seeds are primarily collected by women. In contrast, men gather materials for furniture and construction, and both men and women collect fruit and medicines (Gakou *et al.*, 1994). Collection of leaves and fruit from trees is generally done by groups of women from the same or related compounds working by hand or using a long stick with a sharp blade tied on the end in order to reach higher branches. The size of the collection carried on a woman's head is an object of pride and a way

Fig. 7.6 While other ethnic groups sun-dry *Vitellaria* nuts, the Otamari in Diepani, Benin, use ovens. The method requires a lot of fuelwood but allows women to leave the nuts almost unattended for the two-three days required. *K. Schreckenberg*

of obtaining recognition from male and female household members (Bergeret and Ribot, 1990).

Products with a significant market value are collected on special trips, while those which are seldom or never commercialized are collected as and when convenient (Schreckenberg, 1996). Men tend to collect products on organized trips, while women gather products in passing or on slight detours to a known tree on the way to or from the fields. When harvesting *Vitellaria* nuts, women often start collecting in bush areas surrounding the village where the tenure is collective. The weak tenure status of these areas affords poor households access to this resource (Serpantié, 1997b), but as they are usually located further away than the fields, the collection requires more time. As the season progresses and the plant cover grows tall, women prefer to gather in their fields where the fruit can be easily picked from the ground. But when time permits they also plan expeditions requiring several hours to areas where they hope no collection has yet taken place.

The fact that the activities are differentiated by gender may lead to a significant difference in men's and women's perceptions of who collects NTFPs and how frequently. In Mali, for example, men were aware of most of the products collected by women, but underestimated the frequency of their collection. Women did not mention all the products collected by men. Both genders had similar perceptions of who collected the majority of the three regularly used items, i.e. fuelwood, food and fodder. However, perceptions concerning the collection of all irregularly used items (construction materials, medicines, other products) differed greatly between men and women. Women showed little awareness that men actively collected construction materials for personal or commercial purposes (Gakou *et al.*, 1994).

The fact that collecting forest products requires no cash investment is a strong incentive for both women and men, especially among the poor, immigrants and young adults. In Dimolo and Djèbénao in southwestern Burkina Faso, *Vitellaria*-based activities were more common than making beer or preparing food for sale because the production required no initial funds (Crélerot, 1995). Yet, for reasons probably due to availability of time or access to resources, the quantities collected by poor women were slightly lower than those collected by better-off women. In turn, *Vitellaria*-related activities from September to November generated a higher proportion of total income for poor women (42 percent) than for better-off women (33 percent). In Benin, NTFP-based activities attract young women who cannot afford the capital investment needed to embark on alternative income-generating activities, as well as older women who may lack physical or financial resources (Schreckenberg, 1996). Most of the male gatherers involved in these activities were either recent immigrants or young unmarried men, who did not yet have their own agricultural plots. The high demand for *Vitellaria* nuts in Côte d'Ivoire has aroused young men's interest and they now compete with women to collect them (Bliss and Gaesing, 1992). They may also sell the kernels direct to wholesalers without drying them sufficiently and this poor quality produce may give Côte d'Ivoire's kernels a bad

reputation among international buyers. By selling the kernels rather than the processed butter, both households and the region as a whole are losing out on the value added by women during processing.

Consumption

Quantities of NTFPs collected and consumed and species preference vary according to ethnic group. Peulh families in Senegal may stock up to 90 kg of *Cassia obtusifolia* leaves, 50 kg of *Tamarindus indica* leaves and 200 kg of *Adansonia digitata* fruit. In contrast, Wolof women in the same area rely on their peanut harvest and small ruminant production and keep only small reserves of forest products. Whereas Socé people favour baobab leaves as the main ingredient of sauces for the staple cereal dish, Peulh and Wolof prefer the exudate of *Sterculia setigera* for that purpose (Bergeret and Ribot, 1990).

Differences in consumption values may be related not only to preference but also to the resource level of families or even ethnic communities. For instance, the value of NTFPs consumed annually by the Otamari, an immigrant group in Diepani, Benin, was almost twice as high (12 472 FCFA) as for the Anii (6 430 FCFA) in Kodowari, an indigenous village in the same area (Schreckenberg, 1996). The Otamari also relied on home production for 67 percent of processed forest products, whereas the Anii produced only 15 percent of these products at home and bought 85 percent of them in the markets. Lower NTFP consumption by Anii women, who have mostly lost the skills needed to process the products for themselves, may be due to a more restricted use of these products. In addition, their greater wealth allows them to buy available substitutes such as groundnut oil, 'Maggi' stock cubes and manufactured soap. While homemade *Vitellaria* butter, also the cheapest fat available locally, was used for all cooking purposes in Otamari households, Anii women only purchased it for deep-frying cakes, and preferred palm oil or even groundnut oil, when available, for other purposes.

Women are generally responsible for the sauce ingredients accompanying the daily staple cereal provided by the household heads. In Kumbija, Senegal, the woman in charge of meals can meet her objective in three ways: by drawing on her individual peanut crop and compound or '*bas-fond*' garden, by harvesting wild food or by the sale of the chickens or small ruminants she has raised. Wolof women tend to rely on purchases rather than collected forest products or the produce of compound gardens. In contrast, Peulh and Socé women depend more on collected than purchased items (Bergeret and Ribot, 1990). The size of a woman's stocks of forest products depends on how much time she has been able to devote to collecting activities. The reserves of single wives and those with heavy family responsibilities (young children, old parents and seasonally migrant husbands) are likely to be small. They may also be small in the case of wealthy or large households which can afford to purchase the desired items.

Fig. 7.7 A '*dero*', the traditional local granary with walls made of a dried clay and straw mixture, provides excellent long-term storage for *Vitellaria* nuts in Lira, Uganda. *E. Masters*

Fig. 7.8 After shelling, *Vitellaria* kernels are quickly roasted and then coarsely pounded (foreground). The product is then ground to produce a chocolate-like paste (background), Thiougou, Burkina Faso. The paste will then be mixed vigorously with first hot and then cold water to separate out the solid white fat.
J.-M. Boffa

Processing

Virtually all forest-related processing activities are carried out by women. Processing of *Vitellaria* nuts and *Parkia* seeds is mostly done by women (Schreckenberg, 1996; Masters, 1992). In Benin, men were responsible for palm wine distillation and for woven objects. The techniques used by women in the processing of NTFPs are often labour-intensive and physically strenuous, involving pounding, grinding and stirring, and requiring the collection of large quantities of fuelwood and water. The capital needed for undertaking processing activities varies and can be a major hurdle for women's participation. In southwestern Burkina Faso, poor women sold significantly more unprocessed *Vitellaria* nuts, and sold them sooner after collection, than women of higher economic status (Crélerot, 1995). In Benin, as is probably also the case in many other places, Schreckenberg (1996) found that women cannot afford the initial outlay without contracting loans and they then have to sell the processed product before they can repeat the activity. However, because they often sell their products on credit and do not calculate their profits, they can easily fall into the credit trap and lose their capital completely. And any factor (illness, pregnancy, unexpected expenditure) disrupting this earning and spending cycle can lead to impoverishment.

The formation of a women's group in Dimolo, Burkina Faso, had a significantly positive impact on the women's collective investment capacity. The group was able to open a bank account, register officially as an organized group and purchase a cereal mill at a government-discounted price. The purchase of *Vitellaria* nuts by the state through the *Caisse de stabilisation des prix et des produits agricoles* (Agricultural Pricing and Marketing Board) had also been a primary factor for the development of the group, and contributed to a regular income for the members. However, with the discontinuation of the state commercialization programme in 1992, and the low and fluctuating prices of nuts, the women continued marketing cereals but there was concern for the long-term viability of the group (Crélerot, 1995). The demand for credit provision to sustain *Vitellaria*-related activities is high and rural credit programmes have been highly successful with loan recovery rates of over 90 percent (Pugansoa and Amuah, 1991; Kisakye *et al.*, 1997).

Marketing

Rural people's participation in NTFP marketing is subject to ethnic variations. In Bassila, Benin, all women were involved in collecting *Vitellaria* products for sale, but beyond this 83 percent of Peulh women were involved in a further three or four NTFP activities, while only 24-46 percent of the neighbouring Anii, Otamari and Logba women undertook one or two further NTFP-based activities (Schreckenberg, 1996). Similarly, due to the minor importance of agriculture in their distinct lifestyle, Peulh herders were twice as likely to be involved in NTFP-

based activities as men from the other ethnic groups. Ironically, while *Vitellaria*-related activities used to be the exclusive domain of ethnic groups with no cattle production component, Peulh women in the Bassila area of Benin are known as expert makers of *Vitellaria* butter.

Regardless of ethnic group, marketing of NTFPs is predominantly a women's activity in West Africa. In the case of Zitenga, Burkina Faso, 91 percent of local market activities are handled by women (Guinko and Pasgo, 1992). In the market at Diepani, Benin, a village dominated by the Otamari immigrant group, men represented 12.3 percent of sellers. However, only 1 out of 625 sellers interviewed was male in Kodowari, a nearby Anii village where the gender division of labour is more pronounced (Schreckenberg, 1996).

Fig. 7.9 The white *Vitellaria* fat is washed several times and then shaped into different forms, depending on the region. The Peulh near Bassila, Benin, use small calebashes to make butter pats, sold here together with some whole *Vitellaria* fruit gathered on the way to market.
K. Schreckenberg

Forest products are relatively more important to women than men in The Gambia, as 63 percent of village income obtained from the sale of forest products was obtained by women and 37 percent by men. Taking into account other income sources such as sale of farm produce, gifts and waged labour, forest products contributed over 50 percent of women's earnings as compared with less than 25 percent for men. Madge (1995) also noted the influence of technical knowledge, wealth and household size on the levels of income generated by forest product collection. Christian women originating from nearby islands collected riverine products, while Muslim women who had migrated from forested areas were unaccustomed to water and gathered forest products. Women from households with low resources collected products to be sold daily. In contrast, women from wealthier families could afford to market products the income from which would not become available until a few weeks later via transactions with intermediaries. Finally, women from small households responsible for a larger share of domestic chores and farm labour had less time available to dedicate to collecting than those of larger households.

Contributing to the ongoing general debate on how increased household income improves the nutritional status of children, Crélerot (1995) made a first attempt to investigate the association between women's *Vitellaria*-related activities and children's welfare in rural Burkina Faso. Whether mothers used *Vitellaria* butter mostly for home consumption or for commercialization did not have a significant impact on the frequency of butter consumption and the nutritional status of young children. Yet, children consistently consumed more butter in households where butter was mostly marketed than in those where it was mainly consumed at home (but not in a statistically significant manner). In addition, the variety of foods in children's diets, women's monthly purchases, and child-related expenses did not significantly vary in the two groups of women. However, the study was undertaken in a year of low production and market value; it is therefore possible that *Vitellaria* nuts play a more significant economic role in women's purchasing power in better years. There was no relationship between the time allocated to *Vitellaria*-related activities and children's nutritional health. Rather, the nutritional status of children was more closely related to women's economic level than to the use of *Vitellaria* products.

It was positively associated with higher diet diversity and frequency of animal product consumption.

An important aspect in the social organization of NTFP gathering, processing, and marketing is the interdependence of users of different gender, age and ethnic group (Schreckenberg, 1996). Skills are acquired through cooperation in joint activities and passed from mother to daughter, father to son, and between co-wives or friends. Interdependence is also evident in the complex network of specialized actors, from suppliers of raw materials through processors to sellers, as actors rely on one another. This interdependence is also financial. Women often pay the suppliers of raw materials only after they have marketed the processed products, so that sales are done on credit. This is particularly common between family members and near neighbours, and is considered more risky between strangers and distant neighbours where payment can be less easily forthcoming. Women are, however, vulnerable to the consistency of suppliers (Schreckenberg, 1996). Interdependence can also occur between ethnic groups. For example, the indigenous Anii in Kodowari, Benin, are active in the sale of raw and processed agricultural products, but rely on Peulh women for the processing of most NTFPs, unlike the Otamari and Logba who process them themselves.

Knowledge of the medicinal and veterinary uses of plants is usually confined to adults, and the competence of specific individuals is recognized by villagers of Kumbija, Senegal (Bergeret and Ribot, 1990). Knowledge is systematically extensive among Peulh groups, while it varies according to families among Socé and Wolof households which are more agriculturally oriented.

Socio-cultural and spiritual values of parkland products

Fig. 7.10 The social importance of trees is not always recognized. Meetings often take place in the shade of large, conspicuous village trees.
R. Faidutti

Parkland trees do not only play subsistence and commercial roles. Trees and forests in general are present in all aspects of culture including language, history, art, religion, medicine, politics, etc. (Falconer, 1990). Cultural values attached to forests can hardly be separated from their more material functions. This section illustrates a few of the symbolic and socio-cultural values people attach to trees and forests.

Products derived from trees are used as investments in successful community integration and social relationships. For example, in The Gambia the exchange of at least a portion of fish and hunted meat harvests with other households and relatives was often more valued by individuals than sale, as it builds and

maintains long-term social bonds which make reciprocity possible in times of need (Madge, 1995). Such investments and the redistribution mechanism result in reduced risk and continued access to resources. Typical parkland products such as *P. biglobosa soumbala* and *V. paradoxa* butter are kept for social needs such as gifts for births and weddings, or dowries (Crélerot, 1995; A.S. Ouédraogo, 1995).

Fig. 7.11 Cool shady conditions provided by large tree canopies are ideal for rural Sahelian markets.
R. Faidutti

Trees are a part of the landscape which traditionally carry an element of sacredness. As such they are often regarded as a link between the living and the dead and a residence of spirits, for example of ancestors or important historical figures. Thus, a variety of social, cultural and religious activities are held under sacred trees or in sacred forest sites. Each village in West Africa has an '*arbre à palabres*' (discussion tree), where political and social meetings are held and political, judicial and social decisions made. Several studies report on the importance of sacred groves as sites for initiation rites and ceremonies where moral and cultural values and practices are taught to younger generations. Lebbie and Freudenberger (1996) describe several types of sacred forests used by traditional gender-based village organizations. Their functions include training in matters concerned with relations with nature and the use of natural resources, warfare, behaviour of young women with their future husbands and the village community, and household and child care. They can also be the location for foetal burial, women's fertility association meetings and prayer ceremonies, or be protected due to the occurrence of legendary or mythical events. They are also a site for ritual healings and a place where villagers find specific plant medicines.

In villagers'eyes the most important value of some savanna woodlands in Zimbabwe consists in the sacred areas they contain. The conservation of these areas according to ancestral guidance is essential for good rainfall, upon which productivity relies. Therefore, an important function of these sacred forests is the annual rain-making ceremonies (Hot Springs Working Group, 1995). Rituals for land fertility and good harvests may also be held in similar sites.

A number of forest/tree products are used in traditional religious rituals and healing treatments (Stoller and Olkes, 1987). For instance, the consumption of palm wine was valuable in customary rites concerning marriage and funeral ceremonies and the bark of *Kaba senegalensis* was used in children's naming ceremonies (Madge, 1995). In northern Uganda, when *Vitellaria* nuts are very scarce, some people have adamantly refused to sell their remaining stocks, at any price, in favour of saving them to process butter for traditional ceremonies (Masters, 1999).

Folklore, tales, and proverbs also reveal the major symbolic significance of trees in West African thought (Calame-Griaule, 1980; Kaboré, 1987). Their symbolic function can be fecundity, power to bestow life, death and rebirth, wisdom, authority and custom. For communities which have migrated, trees such as *Ceiba*

pentandra (Trincaz, 1980) or *V. paradoxa* (Bergeret and Ribot, 1990) believed to come from the community's original location serve the same purposes. They therefore maintain cultural continuity and villages are sometimes founded around these large trees.

Analysis of costs and benefits of parkland production

Farmers recognize the value of maintaining trees in their agroecosystems and have practised tree conservation for centuries. In turn, scientists are interested in measuring the overall advantages and disadvantages associated with mixed tree/crop systems in comparison with pure annual cropping systems. Such evidence can have a significant impact on policy formulation.

Estimates are complicated by the many sources of annual variation in factors governing tree and crop production and tree-crop interactions, many of which were outlined in Chapters 3 and 4. For a given geographical area and the characteristics of its soil and parkland tree cover, these variables include nature of the crop, horizontal crop rotation, tree density changes over time, tree species, tree size, rainfall and climatological conditions. Crop yields are subject to agricultural practices and climatic conditions. The fruit production of parkland trees fluctuates heavily, depending on environmental and genetic conditions.

Physical gains and losses associated with *Vitellaria* and *Parkia* parklands in southern Mali were quantified in economic terms by Bagnoud *et al.* (1995b). The study adopted tree-crop interface models based on a series of existing data including:

Fig. 7.12 Marketing traditional soap made from palm kernel oil and ash, Bassila, Benin. ***K. Schreckenberg***

Fig. 7.13 Marketing *Faidherbia albida* pods in Mopti, Mali. ***R. Peltier***

- Kater and colleagues' (1992) subcanopy crop yield reduction;
- Kapp's (1987) crop yield reduction in the zone between crown edge and 1.8 times the canopy radius from the trunk; and
- assumptions on missing crop yield and crop reduction data.

Taking into account the lowest annual market values of annual and tree crops, gains were three to four times higher than losses on average, resulting in a range of gross returns from 4 800 to 10 600 FCFA/ha/year over a complete crop rotation (three to five years) in the three villages considered. Inputs from *Parkia* trees were two to

three times as high as those of *Vitellaria* trees, so that the economic return rose significantly with increasing *P. biglobosa* densities. Wood accounted for only 5 percent of gains. In the net economic return which discounted costs of chemical inputs, agricultural machinery and traction (but not labour), gains were 5 to 11 times higher than losses. The analysis of gross returns is considered more important by farmers, however, as these fixed costs are indispensable in their production systems. Both gross and net balances were less positive when highest market prices were used, and it was assumed that farmers could stock their harvests.

Studies in Burkina Faso showed that yield depression measured under *Vitellaria* canopies 4.5-5.5 m in diameter and with densities of 12-31 trees/ha was compensated by the slight grain yield increase in the area surrounding crowns, resulting in a small positive field-scale influence of trees on crop yields (Boffa *et al.*, 1999). This surplus amounted to 300-4 800 FCFA. Average kernel production measured on 54 randomly selected trees over three years was 2.4 kg/tree. Thus, based on *Vitellaria* densities averaged across family and women's fields, kernel production per hectare was 52 kg (Boffa *et al.*, 1996a). *Vitellaria* parkland production including both tree influence on crop yields and kernel production was, therefore, associated with an economic gain of between 1 700 and 6 200 FCFA if kernels were sold at harvest time, and 3 000-7 500 FCFA if they were sold at the highest seasonal prices. These figures would be slightly higher if the kernels were processed and sold as butter. However, they do not include gains from the few *P. biglobosa* trees and other species found in these fields. *Parkia* products (seeds and flour) are worth five times the average price of *Vitellaria* nuts (Lamien *et al.*, 1996).

Based on the estimate that 8 *Vitellaria paradoxa* and 2 *Parkia biglobosa* trees/ha produce 5 kg of kernels and 25 kg of fruit respectively, Kessler (1992) estimated that these parkland products would yield about 8 000 FCFA, while causing a 6 percent reduction in sorghum yields costed at 1 500 to 3 000 FCFA depending on average crop yields. Parkland trees would therefore be associated with a benefit of 5 000 to 6 500 FCFA per hectare.

In spite of the differences in production measurements or references used, all three studies demonstrate the economic profitability of maintaining *V. paradoxa* and *P. biglobosa* parkland trees in crop fields. Tree production more than compensates for the possible negative influence on crop yields. Benefits may accrue to women only or to both female and male household heads or members, depending on local tree tenure arrangements. A knowledge of the specific intra-household distribution of tree-related rights is therefore necessary to arrive

Fig. 7.14 Young girl selling *Adansonia digitata* leaves. *K. Schreckenberg*

Fig. 7. 15 Boiled *Borassus aethiopum* seedlings for sale. *K. Schreckenberg*

at a complete analysis. Economic analyses have so far been limited to only these parkland types and are based on crop production data collected in single years. Ideally they should be carried out for other prominent parkland species on a multiple-year basis in order to reflect the long-term scale of farmers' agroforestry strategies. The economic value of maintaining *F. albida* in parklands should most often be positive, due to its generally positive effect on crop yields and the production of fodder (pods and foliage) and fuelwood. This could easily be established from the existing data.

Parkland resources matter to local people in a number of ways which are not always recognized. There are direct use values including consumption and sale, indirect use values consisting of environmental functions, and non-use values, i.e. cultural, religious and existence values (Pearce *et al.*, 1989). Most of the available studies including those referred to above focus on the value of resources which are marketed. Giving values to subsistence uses may be difficult if the resource is not commercialized or cannot be substituted by a marketed commodity. In Kenya, participatory environmental valuation or contingent ranking was used in order to estimate the values of non-traded products of the Oldonyo Orok Forest (Emerton, 1996). The various forest uses or activities were depicted by pictures, which were ranked by villagers according to their importance. Their financial value was then estimated against a 'yardstick' chosen among locally significant and easy-to-monetize commodities. In this particular case, grazing and water worth KES 2 000 (US$40) per household were considered priority resources, and the annual benefits of forest use to the local pastoralist community (1 000 people) were estimated at KES 5 million. Consequently, allowing local communities to maintain these values is a strong incentive for the conservation and sustainable management of this forest.

The value of indirect environmental functions is more difficult to establish, as the consequences of the resource's loss for related ecological services and economic activities need to be assessed (Guijt *et al.*, 1995). Non-use values of forest lands are often as or more important to rural communities than their economic value and are also difficult to estimate. Methods rely on estimates of what farmers are willing to pay for them. However, the essential values of resources may simply not be quantifiable. Much like natural forests, agroforestry parklands provide a variety of subsistence uses and market activities, as well as significant environmental services and socio-cultural and spiritual values. Clearly, the continued maintenance of many parklands is in itself an indication of their value to the local people, even if the exact values are difficult to quantify.

Summary

Consumption of parkland foods is important in terms of frequency of use, percentage of consumers, and quantities involved. This is illustrated by consumption patterns for *Vitellaria paradoxa* butter and *Parkia biglobosa* seeds, respectively around 10 and 3.6 kg/yr/person in West Africa. Parkland foods provide a high percentage of specific nutritional requirements, especially micronutrients. They contribute to higher palatability of the staple foods they accompany, and a higher dietary diversity. As they often become available during the hungry season, and some of them can be processed for storage and eaten throughout the year, these foods enhance people's seasonal food intake. Farmers also rely on them during emergencies such as famines and illnesses.

Traditional medical systems include the use of most parkland (and forest) species. An abundant literature exists on the medicinal treatments which parkland species are used for, but relatively little is available on use patterns and relative importance, knowledge regarding proper processing, chemical composition and pharmacological suitability, effectiveness and evaluation of cost relative to modern practices.

Many parkland products are marketed locally but good quantitative data on their commercialization are relatively rare. The examples of *Pterocarpus erinaceus, Borassus aethiopum* and *Hyphaene thebaica* are reviewed in this report. Generally few people are involved in tree-related marketing activities on a regular basis, but many participate in such activities on a seasonal basis. Minimum annual income generated from parkland items may be in the order of US$10-35 for the second group. Parkland products can cover up to 20 percent of weekly expenses for those regularly involved in commercialization, and for those involved on a seasonal basis they may be the source of large lump sums to cover annual expenditures, savings and loan repayments.

Two parkland products are exported internationally in quantities of several tens of thousands of tons annually, generating important national revenues. Gum arabic from *Acacia senegal* is a water-soluble exudate produced predominantly in Sudan and used in numerous food, pharmaceutical, cosmetics and other industries. *Karité* or shea (*Vitellaria paradoxa*) nuts make a high quality vegetable butter. Besides being a primary cooking fat in semi-arid West Africa, its main international application is as a cocoa butter equivalent (CBE) used by European and Japanese industries, and increasingly also as a base for cosmetics products. Constraints to the development of the *Vitellaria* market include an irregular annual supply of low quality, a recent decline in chocolate demand in Eastern Europe, dependence on cocoa markets and competition from other CBEs. However, the adoption of European norms authorizing the use of *Vitellaria* for cocoa butter substitution, and improved quality and differentiated supply of butter for the cosmetics sector, as well as domestic opportunities, could promote this market.

Activities for the production and commercialization of parkland products are generally divided by gender. Men tend to be involved in collection and other tasks which require skill and risk, while women are responsible for most of the less risky collection, processing and commercialization activities. Compared with men, a higher proportion of women's income is usually related to parkland production.

The fact that gathering activities do not require initial cash investment is an incentive for poor segments of village populations (poor women, immigrants and unmarried individuals). They provide a relatively higher percentage of income

(despite sometimes lower absolute quantities) for the poor than for groups with a higher resource level. Quantities gathered are also determined by consumption patterns and food preferences which can be linked to ethnic groups. Wealthier women have the time and labour availability to invest major efforts in the collection and commercialization of parkland products, yet they can also afford commercial substitutes and may prefer to rely on purchased rather than gathered foods. In contrast, due to their numerous responsibilities and limited labour, poor women may have limited time to dedicate to NTFP activities. Similarly, poor women choose processing activities which do not require investment, or may take out loans to do so which, however, make them vulnerable to impoverishment. They also engage in daily marketing activities which yield immediate returns, while wealthier women can afford to market items for which payment is delayed. Collection, processing and commercialization activities surrounding parkland products are the source of a strong interdependence between participants which promotes social integration, transfer of technical knowledge and economic exchanges.

Available cost-benefit analyses all point to the economic profitability of integrating trees in crop fields, but have focused so far only on *Vitellaria paradoxa* and *Parkia biglobosa*. Analyses have mostly only taken direct use values into account, because indirect use values, such as environmental functions, and non-use values such as cultural and religious functions are more difficult to evaluate.

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER VIII

The significance of agroforestry parklands

Agroforestry parklands are widespread ...

Agroforestry parklands, broadly defined as areas where scattered multipurpose trees occur on farmlands as a result of farmer selection and protection, are widespread throughout the world. On a land area basis, they may represent one of the most extensive farming systems in the tropics. They are the dominant farming systems in semi-arid West Africa and cover the vast majority of cultivated area in Sahelian countries. This is reflected in the fact that most of the literature on agroforestry parklands deals with West African systems. In contrast with exclusively silvipastoral systems, these parklands include a long-term cultivation (and fallow) component, and have been described at length since they were first discovered by explorers in the early 1800s.

... and important for rural food security,

Agricultural production in this region, which is mainly subsistence-oriented, mostly occurs under the discontinuous cover of parkland trees, so that these agroforestry systems contribute to the sustenance of millions of livelihoods in Africa alone. They also represent a major source, both in number and volume, of timber and non-timber forest products, which contribute to the food security of local communities and individuals. Current trends of growing pressure on limited natural forest resources coupled with a rising demand for forest products suggest that reliance on on-farm forest resources is likely to increase in the future. Certain parkland products, including gums, oils, proteins, fruit and drinks, are among the main and most frequently consumed items in their respective food categories by a majority of people, especially in rural areas. Some very popular products such as *Vitellaria paradoxa* butter and *Parkia biglobosa* spice are consumed throughout their distributional range, while patterns of consumption for others are more limited geographically. Edible parkland products are not only critical in supplementing the nutritional value of basic staple foods in lipids, proteins and micronutrients, but they also diversify diets and enhance people's seasonal food balance since they become available at different times of the year.

... for income generation,

NTFP production in agroforestry parklands generates significant income for a variety of local economic actors. A wide range of parkland products are intensively commercialized. Although a coordinated evaluation of the importance of individual commodity markets has not been carried out, available figures point to income-earning opportunities which are far from insignificant for individual households, communities and local economies. Income from parkland products can amount to 25 percent or more of the total income of non-specialized individual producers. A few products such as gum arabic and *Vitellaria* nuts are internationally traded and represent primary export earnings for a number of Sahelian economies.

... and are particularly relied on by vulnerable social groups.

Parkland production also plays a fundamental role in ensuring social equality and cultural stability. Specific social groups including women, the poor, immigrants and young adults, are particularly involved in the gathering and sometimes the processing of parkland products, because these activities require no cash investment. Marketing of these products is also predominantly a woman's activity. Parkland products tend to represent a higher proportion of women's than men's income, and can have an impact on women's economic level and the nutritional status of children. Production and commercialization activities of parkland products promote interactions between gender, age and ethnic groups and encourage transfer of indigenous technical knowledge, economic exchanges and social integration. Parkland trees also contribute to the reproduction of cultural and spiritual values in traditional rural societies.

A rich pool of forest genetic diversity has been actively maintained by farmers in these systems.

Although frequently dominated by just one or a few species, parklands include a large number of woody species, often up to 40-50 in the cultivation cycle alone. Most parkland species have a wide distribution range, occurring either in very localized or continuous patterns. They are, therefore, a very biodiverse agro-ecosystem with a high potential for biodiversity conservation across the region. Far from being residual tree populations from a one-time land clearing process, agroforestry parklands represent an elaborate manipulation of nature to meet

farmer needs which reflects hundreds of years of accumulated knowledge and experience of relatively complex ecosystems. Even though additional studies on the topic are desirable, there is little doubt that parkland management has been crucial in promoting and maintaining the distribution and intra-specific genetic variation of tree species composing these systems. Agroforestry parklands should therefore be considered a reservoir of forest genetic diversity conserved by a dynamic and sustainable land-use system.

Because their positive ecological effect is only tangible in the long term, current preservation efforts are critical.

Parkland trees play a significant role in maintaining the ecological sustainability of farming systems in the long term, i.e. over one or more generations. They contribute to improving the physical, biological and chemical fertility characteristics of surrounding soils through a variety of processes. Data on the buildup of soil fertility and microclimate properties over the life of trees demonstrate that benefits are only realized over a long period. Thus efforts to conserve and enrich existing parklands and to establish new ones are particularly critical.

Dynamic systems

Parklands may have expanded in area but tree density and regeneration rates have declined, ...

In Sahelian countries, the expansion of cultivation over the last few decades into frontier areas, river basins freed from onchocerciasis, and the northern (sometimes marginal) lands, suggests that parklands may have expanded on a land area basis. However, qualitative assessments, farmer perceptions, and a few quantitative studies indicate that parkland tree densities have significantly declined in past decades and that they are characterized by a predominance of old trees and a lack of regeneration. This may have been accompanied by a decline or disappearance of forest species at the local level.

...but the ways in which parkland dynamics are analysed depend on the spatial and temporal scales used.

In order to prescribe appropriate management and conservation measures, parkland dynamics need to be assessed at a variety of different time scales. Rather than being a sign of parkland degradation, for example, a decline in tree density may be inherent to farmers' long-term strategies for developing parklands with appropriate tree-crop combinations and high fruit production. This is particularly true for parklands sustained through the alternation of cultivation and fallow cycles.

Their capacity to support continuous cultivation is the key to their sustainability.

Parkland systems differ in the amount of land they require to be sustained and in their capacity to support increased human pressure. Thus high population densities, and the ensuing land-use intensification, can have a positive effect on the density and regeneration of *Faidherbia albida* parklands, which are suited to permanent cultivation. In contrast, *Vitellaria paradoxa* and *Parkia biglobosa* parklands, which rely on fallow periods for soil fertility restoration and renewal of tree cover, are particularly at risk of degradation and impoverishment with increasing population density and fallow reduction. Nevertheless, even these relatively extensive systems can absorb

high levels of population growth, provided more intensive soil and tree management techniques are applied to permit longer cropping intervals, reduce risks, and sustain a diversity of tree products and services.

Parkland systems do not evolve unilinearly, but respond to a wide range of opportunities.

The decline of parkland cover in semi-arid West Africa is by no means uniform and conceals existing islands of active parkland regeneration, many of which have probably not been recorded. Far from being fated to deteriorate, these systems display a high degree of resilience. Farmers responsible for their creation and maintenance respond dynamically to a variety of natural, economic, socio-cultural, technical, demographic and political parameters. This implies that there is probably no single recipe to ensure the long-term survival of agroforestry parklands. Rather, a variety of factors can, if used wisely in correctly defined geographical settings, offer farmers positive conditions for preserving these systems.

Parkland classification

A recent field of study characterized by methodological challenges ...

The definition of agroforestry parklands is an inclusive concept with sometimes unclear boundaries and distinctions between subsystems. Because of their mixed human and natural origins, and their crop and forestry components, parklands have in the past received variable recognition in vegetation studies and have not been associated with any single traditional discipline. This may have diluted the attention given to these systems by the research and development community and policy-makers. Thus parklands have only recently moved on to the agroforestry research agenda as an integral object of study, but this remains beset by practical challenges of how to cope with their diverse nature and overall complexity.

... with a need to refine and operationalize classification methods to better exploit local development potential of the systems ...

Several classification methods based on intensity of tree management, tree uses, spatial variation linked to soil management type, and ethnic identity, have been used to distinguish parkland types. However, they are often described in a very static way in the literature and are difficult to operationalize in the field. These typologies need to be tested, adapted and refined to reflect farmers' changing parkland management practices, and to enable them to be used as tools for the assessment and promotion of improved management potential. A closer link might be established, for example, between the intensity of parkland management (particularly planting practices) and the potential to domesticate several promising species. Characterization efforts and assessments of parkland management strategies also need to be carried out at increasingly finer units from the ethnic group to the village, household and subhousehold levels within the wider economic and institutional context.

... using multidisciplinary approaches.

This has methodological implications. Characterization techniques need to cover a range of different scales from the region, *terroir* and parkland unit down to the field,

plot and individual tree level. Parkland studies also demand a strong multidisciplinary approach and wide collaboration between various sciences including morphogeology, soil science, agronomy, forestry, geography, history, socio-economics, animal science, remote sensing and GIS technology.

The development of sound conservation and improvement strategies requires collection of longitudinal data...

In sharp contrast to their importance in semi-arid West Africa, there is a deplorable lack of longitudinal data comparing tree cover (density, age composition, etc.) and management at distinct time intervals which could help to assess the past and recent evolution of parklands and assist the R&D community in setting priorities to support their sustainability. Historical data will also be needed on the changes in social, political and economic context which may have accompanied resource management in communities. This implies a need to refine historical research methodologies for the collection of oral and documentary evidence.

... and coordinated regional assessments.

Characterization studies and information on West African parklands are relatively abundant and reflect the high diversity of floristic composition, density and age structure in these systems. But these often in-depth studies remain spatially and temporally fragmented and of relatively limited geographical scope. Their use of a variety of field and remote sensing techniques makes comparisons and synthesis difficult. This results in an incomplete picture of the condition of parklands at the scale of the Sahel and Sudan zones. Regionally-based quantitative data on the actual geographical extent of parklands, relative frequency and importance of parkland species, parkland stocking rates, and age structure, are necessary to guide appropriate research and development efforts, particularly given the transnational character of parkland biodiversity and intra-specific diversity.

A comprehensive regional assessment based on common classification procedures would provide the scientific basis needed to evaluate the condition of agroforestry parklands and develop conservation and improvement strategies. Such an assessment could be undertaken by individual countries in a regionally coordinated fashion through remote sensing and field studies in representative agroecological and socio-ethnic zones. Countries would be in a better position to evaluate the national area falling under this land management system, assess priorities, and renew their commitment to sustaining and enhancing it. The data could also help to make agricultural and economic policies target parkland systems more specifically and take into account their particular needs. Finally, a regional assessment would strengthen global recognition of parklands, and support regional or international frameworks for collaboration on parkland-related research and development.

Conservation and reproduction of agroforestry parklands

Economic incentives are a powerful driving force for the reproduction of agroforestry parklands ...

There is ample evidence to show that farmers invest actively in the protection and reproduction of parklands whenever they perceive that trees and their products

become more valuable whether because of increased demand or declining availability. They also strengthen or construct institutional arrangements and maintain the necessary knowledge base for the management of these systems. In contrast, farmers tend to neglect their forest resources and favour alternative agricultural practices, items of consumption and income-earning activities, when these yield higher benefits than parkland-related activities. Factors of particular importance in their decision-making are lower costs, higher revenues, lower labour expenditure, better product availability, greater subsistence priority, preferred taste, etc. External parameters such as markets, external pressure on village resources, migration and relations with urban centres, also strongly influence the relative value of parkland trees.

... which should be actively promoted through a domestic political will to use and commercialize parkland products.

The direct relationship between market demand and economic incentives associated with parkland products suggests this as an important way of influencing the conservation and regeneration of parkland resources. This relationship is not new. More detailed historical research on these tree crop economies could contribute to an understanding of how various forms of parklands were born out of traditional mercantilist production and marketing structures and routes within Sub-Saharan Africa, and sometimes beyond. Economic sectors or systems for parkland crops (gums, oils, fruit, proteins, drinks, fodder, medicines, etc.) have been unevenly studied and monitored. Some occupy relatively small but significant, resilient niches in the international economy. Others may not have much impact on national economies, but represent a very important source of subsistence and income for local communities and individual households. With the opening up of village economies to the wider society, both regional and international, the commercial development potential of parkland tree crops appears to be under-exploited in national Sahelian economies.

National, bilateral, regional and international institutions should move vigorously towards supporting the development and commercialization of parkland products. In addition, countries ought to promote policies and practical actions to increase the local production, diversity, quality and use of parkland products.

Labour and quality constraints in storage and processing technologies must be alleviated,

Market development for parkland products calls for reliable chains of production which can guarantee product quality and consistent supplies. Collection, processing, and pre- and post-processing storage technologies for parkland products are often time-consuming, labour-intensive, require large amounts of fuel and water, and result in low efficiency, low profitability and sometimes poor price competitiveness. More support should go towards the identification of production and quality constraints, the further development and improvement of appropriate, cost-effective technologies with higher extraction yields, lower investment and labour demands, and durable equipment, as well as the design of appropriate institutional and financial arrangements for the development of village-level production units.

... the various product markets characterized,

Because of their traditional importance, parkland products are generally in popular demand. However, little is known about the constraints and opportunities for their further market development. This requires information on both the products concerned and commercial possibilities. Additional scientific data on the chemical

composition of raw and processed materials and their nutritional, pharmacological and cosmetic characteristics would help to pinpoint their commercial potential and establish product quality requirements. An in-depth national characterization of parkland commodity systems (product flow, market participants, prices, seasons, information systems, product grading systems, processing and transport infrastructure, patterns of consumption and demand, substitution products and processes, etc.) would support an assessment of the potential for improvement of each commodity sector. It may then be possible to identify specific research and policy interventions and to monitor and evaluate their capacity to stimulate these systems. Results need to be communicated to all concerned to update the research, policy and extension agenda and enrich the decision-making process.

...and possibilities for development explored.

With the support of pilot research and commercial operations, market developments could be pursued in the form of diversification of end products, enhanced quality, packaging and image of traditional products to meet expanding urban demand, and the promotion of products through local awareness campaigns. Strengthening producer groups and maintaining a high proportion of profits at the producer level would be essential to encourage farmer participation. Catalysing the development of such initiatives by promoting partnerships with local non-governmental organizations, rural groups and local entrepreneurs, could be an important role for national researchers, particularly in the fields of agroforestry systems, technology and marketing.

Domestication of parkland species may proceed most actively in localized niches of relatively high management intensity.

Trees improved through modern domestication methods may increase farmers' interest in maintaining and expanding their investment in parkland agroforestry. This requires tree planting, however, which is a growing but not strongly rooted practice in the Sahel. Because practices are unlikely to change overnight in these risk-averse systems, researchers could focus on localized niches of increasing management intensity, where demand for germplasm is active. A number of these niches displaying favourable characteristics for parameters such as soil management units, farm type, degree of resource scarcity, access to markets, favourable land and tree tenure, and enabling forest regulations could be identified for promising species. The attributes and functions of trees desired by target groups in these specified environments would then gradually form the basis of specific, adapted domestication strategies. These would need to be preceded or accompanied by the optimization of production, processing and commercialization systems in order to stimulate further demand for improved germplasm. A more precise knowledge of the patterns and impact of indigenous forms of domestication, which have been little studied in agroforestry parklands, would help to set a realistic agenda and clarify the potential of 'modern' domestication.

Where there is a demand for tree planting, government and decentralized seed centres and nurseries need to support it by developing flexibility and responsiveness to the (food, fuelwood, etc.) needs of farmers, and drawing on indigenous knowledge for the propagation of desired parkland species.

Agroforestry parklands will survive and reproduce best where they are sustained by sound institutional frameworks such as the indigenous management systems established by communities.

The management of parkland resources has been upheld by indigenous arrangements concerning access to natural resources both at the community and

individual levels. These arrangements are adapted to local conditions, possess a strong degree of flexibility, and reflect local institutional capacities. They are a major cause for optimism about the future of agroforestry parklands, and should be increasingly recognized and respected. To support these indigenous institutions in their sustainable parkland management, a better understanding is needed of the conditions enabling them to operate and adapt successfully.

Field professionals can assist these flexible systems to move towards more intense levels of tree management ...

An increase in the management intensity of land use, which may be linked to intense population pressure or high resource value, has generally been accompanied by clearly articulated regulation of rights of access to resources, and often a more individualized control. Similarly, where arrangements are secure and unambiguous, parklands have the greatest chance of reproduction, while ambiguous and insecure tenure relations are a disincentive to their maintenance and emergence. Forestry extension and development personnel thus need to acquire a detailed understanding of local land and tree tenure dynamics surrounding parkland resources in order to identify constraints and opportunities for the adoption or enhancement of parkland agroforestry practices.

... by helping multiple actors craft clearly articulated agreements regarding land and tree rights.

In the African context, caution is needed not to equate the individualization of land and tree rights with 'private property' as defined by formal administrative and legal frameworks. Experience shows that individual control, nested in the bundle of overlapping rights to tree crops which have been created by inheritance, labour investment and migration, remains subject to renegotiation and redefinition. These control patterns are guided by economic and social objectives, rather than being sustained by formal laws. Supporting the clarification of tree rights while respecting their possible multiplicity and socio-economic rationale will probably be more fruitful than land and tree privatization programmes, which may sometimes support expropriation by one social group against another.

The apparent paradox of 'complex' indigenous regimes with multiple tenurial niches is their unique flexibility. While farmers borrowing land appear less likely to plant trees in parklands than owners of inherited land, these systems provide a wide range of possibilities for designing mutually appropriate agreements. Forestry practitioners can make a significant contribution in helping individuals and communities negotiate arrangements allowing tree planting and use by these and other secondary rights-holders.

A more difficult and long-term task will be the revision of national forest laws and institutions ...

National forest policies and the way they have been implemented in the Sahel are often greater obstacles to the improved management of agroforestry parklands than indigenous tenure systems. Ambiguous policies have been interpreted as applying to on-farm trees resulting in, often repressive, enforcement of access restrictions and centralized control over parkland resources. Such policies have led farmers to believe that they have limited rights to trees on their own farms and kept them from carrying out basic management activities such as pruning, thinning and coppicing, which are crucial in optimizing their land use systems. As a result, farmers often choose not to plant trees or protect their regeneration.

... to allow improved, decentralized parkland management.

True advances in parkland management cannot take place unless farmers can apply tree management techniques - as dictated by the requirements of crop and tree health and production, as well as underlying goals of subsistence and economic welfare - on agricultural land they traditionally own and control. Despite several breakthroughs in recent policy revisions, a major turnaround in the attitudinal, legislative and institutional features of forest administrations is still necessary. Governments should consider minimizing the degree of intervention in parkland areas where individual landholding rights are recognized, and even find practical legal and administrative means to reward people for developing land through the maintenance and expansion of such agroforestry systems.

A new advisory role for the state ...

Local management institutions provide a strong basis for the establishment of co-management schemes between government and local communities to promote decentralized management of forest lands under communal tenure. Devolving management rights to communities often promotes a higher efficiency of local resource management, but it would be unrealistic to assume that communities are automatically capable of more sustainable and equitable management than currently achieved by the state. Governments should be ready to continue to provide inputs as they assess the limits to local authority, administrative and technical competence, and arbitration capacities. The shift in the role of the state from centralized decision-making to advising and negotiating will also require fundamental changes in attitudes and skills of state officials.

... can only be achieved with adequate training and financial resources.

The process of revising forest policies will inevitably have considerable economic implications at local and national levels which have to be closely examined. The removal of permit requirements from some forest resources may decrease state revenues, while the transfer of resource management and regulation responsibilities to local groups may increase their financial burden. New forms of state assistance for communities will have financial implications, as will the need to improve forestry training, extension and information dissemination. Assessments of the economic impacts of such changes, as well as commitment and financial support from national, regional and international administrations, will thus be necessary.

Parklands are not incompatible with modern cropping techniques. Extension services have a major role to play in the promotion of parkland agroforestry.

There is no inherent incompatibility between trees scattered in fields at appropriate densities and the use of cash crops, modern cropping techniques such as animal traction, or chemical fertilizers. While fertilized cash crop production may displace staple crops, shorten or eliminate fallows, and encourage shorter-term tenure, all of which can be detrimental to parkland sustainability, these technologies can also be applied less negatively with more attention paid to trees and their improved management. A greater effort by extension services and agricultural commodity agencies to include the agroforestry agenda in their promotion of modern agricultural practices is desirable. Results of research on the effect of trees on soil fertility, soil water, crops and microclimate, as well as the importance of indigenous parkland management institutions, should be translated into practical

recommendations and communicated to national and parastatal extension services and field agents.

Agricultural fertilizer policies emphasizing the removal of input subsidies and price controls have had a positive impact on the expansion of *Faidherbia albida* parklands in western Senegal. Although too location-specific to be easily generalizable, the conditions under which similar policies might have positive effects in other parkland types should be investigated.

More research is needed into traditional management techniques, which focus on rejuvenating parklands through natural regeneration ...

Technologies which increase tree and crop productivity will create additional incentives for farmers to invest in parkland agroforestry. Their efficiency and adoptability are likely to be greatest if technology development recognizes and builds upon indigenous management systems. In order to ensure the reproduction of parklands in which rates of tree attrition are higher than recruitment, applied research, development and extension activities should emphasize tree enrichment. This can be achieved either through the planting of species desired by farmers or through the easier, cheaper and more widely applicable technique of protecting natural regeneration. The impact that projects promoting this simple but effective traditional technique have had in communities should convince donors that funding of such projects is key to poverty alleviation, environmental protection, and biodiversity conservation. The conditions under which these projects are successful need to be identified and widely communicated. Research into the kinds of local incentives (prizes, training, tax reduction, etc.) needed to enhance planting and regeneration rates, and into ways in which local groups and administrations can sustain them with minimal outside support, would also be worthwhile.

... and improving the cropping environment through pruning.

In the low soil fertility environment faced by most farmers in the Sahel, tree pruning appears to be an attractive option for improving crop production around tree canopies. Repressive forest policies have probably prevented farmers from practising and experimenting with this and other tree management techniques to realize their full potential. Before it can be widely recommended, research will need to assess the effect of repeated pruning on long-term subcanopy soil fertility and crop performance, as well as on fruit, leaf and wood production.

Biophysical interactions

Intercropping crops and parkland trees is biologically and economically profitable. But more information on production levels could lead to improved management and greater benefits.

Parkland agroforestry is increasingly acknowledged to be a rational production system, practised and improved by Sahelian farmers over many centuries. In spite of methodological difficulties, experiments comparing crop production with and without parkland trees show that increases are experienced with several tree species. A small number of studies indicate that where trees have a negative effect on crop yields, this is more than compensated for by revenues derived from major tree products. Systematic recognition of the importance of such

NTFPs is rather recent, however, and more work is needed to quantify levels of production and to identify the factors responsible for its variation in key parkland species.

To make appropriate recommendations on species choice and management, scientists need a better understanding of tree-crop interactions. These are based on complex biophysical processes ...

Tree-soil interactions usually include the redistribution of nutrients available in the system as well as an overall nutrient enrichment. While the underlying processes are conceptually well established, methodological constraints mean that there is little first-hand experimental evidence to indicate which process predominates. Thus, in areas where spatial redistribution is the primary process of improved soil nutrient content, maximum tree densities may be limited by the overall nutrient pool size, whereas the latter will be less of a constraint in poorly stocked, degraded parklands.

... which have often only been studied in isolation.

Experiments so far have highlighted the individual biophysical mechanisms involved in tree-soil-crop interactions. But they do not yet indicate which mechanisms are likely to have the greatest impact on crop performance and how they interact under different conditions. Several mechanisms can take place simultaneously, either in harmony or in opposition. Thus subcanopy crops may benefit from microclimatic effects of temperature and evapotranspiration reduction, at the same time as being negatively affected by a decrease in incoming solar radiation and more substantial attacks of pathogens caused by higher humidity. In the case of *Faidherbia albida* parklands, experiments indicate that crop production generally improves, whereas the evidence is more controversial for parkland tree species with typical leaf fall phenology. While the importance of microclimatic factors in influencing the outcome of tree-crop associations is acknowledged, a greater understanding is needed of the specific causal relationships which can explain how crop physiology is enhanced in each particular case.

Tree-crop interactions need to be studied over a range of latitudes and a time-span of several years.

In spite of the methodological complexities involved, additional, comprehensive tree-crop interaction experiments are called for. These should measure an increasing number of the biophysical processes involved, including soil fertility, sunlight intensity, temperature, soil and air moisture, and evapotranspiration. Experiments using combinations of artificial shade and fertilizers under and away from parkland trees could further clarify the specific contribution of nutrient enrichment, solar irradiance, and microclimate on crop yields. In order to better understand the conditions which contribute to the improvement, depression, or variability of cereal production under canopies, studies should simultaneously focus on various latitudes, and monitor and compare crop productivity over several years of variable rainfall conditions. The same applies to economic assessments of tree-crop systems, which should reflect the fact that farmers invest in parkland agroforestry as a long-term strategy to provide a buffer against extreme natural events (droughts, pest attacks, etc.) and socio-economic changes. The contribution of trees in the cropping environment, in both biological and economic terms, can be properly evaluated only over the span of several years.

Important factors affecting crop yields include underground competition ...

The extent of competition between tree roots and crops for soil nutrients and water is a question that researchers have hardly started to tackle in parkland situations. This question is probably more relevant to tree species which are biologically active at the same time as crops. However, the fact that *Faidherbia* trees are often pruned, resulting in the extension of their foliation and growth phase into the agricultural season, also makes such investigations necessary for this species. Information on the spatial patterns of root distribution is desirable for various parkland densities and rainfall regimes, and can be generated through trenching experiments in the distinct zones of interactions (sub-canopy, outside edge of canopy, open field).

... and tree size.

Many tree-crop interactions appear to vary depending on the size of the tree involved. Not enough is understood about the relative importance of different interactions under trees of varying sizes. Are there given tree sizes when interactions lead to a positive outcome for intercrops? We already know that islands of high soil fertility under adult trees constitute a significant asset for crop production. But while these may develop naturally under *Faidherbia albida*, in the case of other species they may require crown reduction practices in order to reduce light interception, excessive moisture, or even rainfall interception and evaporation. A more precise investigation of nutrient, water and light dynamics for different tree sizes is needed in parkland conditions to permit more precise management prescriptions (e.g. on fertilizing, pruning, thinning and harvesting) for the various cases of parkland density and tree size.

More work is needed on a wide range of useful species ...

While there has been a relative abundance of studies on *F. albida*, only a handful of studies have been carried out on other equally or more widespread and important parkland species, such as *V. paradoxa*, *P. biglobosa*, *Cordyla pinnata* and *Hyphaene thebaica*. More biophysical research is needed to improve the management of these and other important parkland species with promising socio-economic potential, such as *Borassus aethiopum, Balanites aegyptiaca, Tamarindus indica,* and *Lannea microcarpa*.

... and on scaling up from individual trees to the 'parkland effect'.

Determining the biophysically-optimal densities for different parklands is complex. While further work on the processes involved in fertility amelioration, microclimate and tree-crop interactions at the level of individual trees is essential, it should be accompanied by analyses at the scale of whole parkland systems. The use of GIS and modelling instruments should facilitate the scaling up from the individual tree to the field level. Despite the larger sample size and number of sites required, research into interaction processes and performance should be carried out along a continuum of parkland densities. The need for this scale of analysis is particularly obvious in the study of wind reduction and associated 'parkland effects', which researchers have so far only begun to examine in woodlands. This scale of investigation may reveal another dimension of these systems' efficiency. The verification of these effects in parkland conditions and the assessment of their impact on crop production will greatly contribute to justifying initiatives for the conservation and improvement of these systems.

A landscape with a future

As shown in this review, agroforestry parklands are a rational land-use system developed by farmers over many generations to provide them with subsistence and income-generating products. The many different types of parklands existing in Sub-Saharan Africa today reflect the dynamic nature of these systems and the ability of farmers to adapt them to changes in the natural and socio-economic environment. Their importance as a livelihood buffer, particularly for vulnerable groups in society, and their significance as a rich pool of forest genetic diversity, have increasingly brought them to the attention of the policy-making and research community in recent years. There is a growing interest in promoting the conservation of parklands and in further improving their management to increase the benefits they provide to farmers. To achieve this, changes in legislation may be necessary to allow for the devolution of management to local levels and to turn state forestry services from repressive into essentially advisory bodies. Research into the biophysical interactions underlying parkland productivity can build on indigenous knowledge to provide management prescriptions more precisely attuned to the needs of different environments. And the promotion of markets and improved processing for parkland products will encourage farmers to invest in the further development of their parkland systems. Together these initiatives will enable an already resilient and productive system to play an even greater role in the future livelihoods of rural populations in semi-arid West Africa.

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Agroforestry parklands, traditional agroforestry systems in the Sudano-Sahelian region, are among the most widespread agroforestry systems in African countries south of the Sahara. This FAO Conservation Guide reviews the status of knowledge of these systems and synthesizes the experiences relating to the biophysical, socio-economic and policy aspects of their management. It identifies crucial research needs and promising avenues for further promoting their management, conservation and development. It is expected that future cooperative action will contribute to the sustainability of these agroforestry parklands and to their enhanced role in the livelihoods of rural populations in sub-Saharan Africa.

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